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Teachers' Implementation of Inquiry in Elementary Science Education

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Abstract

This research was an exploratory study of elementary school science education as implemented by five exemplary teachers in grades one through five, situated in four school districts of a Rhode Island Local Systemic Change initiative. This study sought to characterize the presence of inquiry-based teaching consistent with the tenets of constructivism and scientific inquiry as expressed in the book *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (National Research Council, 2000). Qualitative methods were used to conduct the field study. The five exemplary classroom teachers were observed teaching science over a four-month period. The findings from the research describe the nature of science inquiry achieved by the five exemplary teachers in their implementation of hands-on, kit-based elementary school science curricula. This study also illuminates the challenges associated with an inquiry-oriented approach to teaching elementary school science.

Teachers' Implementation of Inquiry in Elementary Science Education

Statement of the Problem

Chapter 1 provides a statement of the purpose of the study, conceptual framework, research questions, and research design. Definitions of terms used throughout this dissertation are also provided.

Documenting and characterizing inquiry instruction as it exists in elementary science classrooms is an appropriate and valued research topic in science educational studies. Inquiry has been a focus and goal of science education reform for the last 40 years in the United States. The use of inquiry as an instructional approach and learning style is complex and presents challenges not only to teachers but also to the educational research field and the evaluation of science education reformation projects.

Over the last 40 years, it has been the goal of science education reform in the United States to achieve scientific literacy for all Americans. The reforms of the 1950s and 1960s began with a brief memo from MIT physicist Jerrold Zacharias in March of 1956 to then president of MIT James Killian outlining a high school physics course (Goldstein, 1992). Within a year, national attention was drawn to the immediate need for educational reform by the successful launch of the Soviet satellite *Sputnik I.* That event marked a turning point in the educational history of the United States (Dow, 1991), and the recently formed National Science Foundation (NSF) received funding to promote the advancement of science, mathematics, and engineering education. NSF funding continued to grow to well over $100,000,000 in support of curriculum projects designed for pre-college learners. Teams of scientists carried out all of these reforms. By the mid-1970s, the NSF reform projects came to an abrupt halt.

The approach by scientists developing NSF-funded curricula projects in the 1960s and 1970s was nontraditional. The distinguished cadre of research scientists turned education reformers bypassed schools of education, school district superintendents, and school district curriculum planners and worked directly with teachers. Scientists viewed themselves as having the most recent knowledge of the content areas and what it meant "to do" science. The textbook-based instruction that schools engaged in was outdated and inconsistent with the types of cognitive skills needed to problem solve in the future.

Bruner (1960) wrote in the *Process of Education* that learning the structure of a discipline would enable learners to develop and experience science in an "honest way" consistent with scientific inquiry. That work served to represent the conceptual and theoretical foundations of curriculum development of that period. A "hands-on," "minds-on" approach to inquiry in the classroom was seen as the preferred approach to learning science.

While inquiry as a way of viewing the world and approaching problems was not new to progressive education, the application of inquiry in the classroom in public schools on a national scale with government support was. Teachers taught science with textbooks. Science was not a prominent subject in the elementary school classroom, and classrooms were not designed for the inquiry envisioned by the curricula developers. The reformers found themselves not only involved in the development of curricula, but also in providing teacher training to ensure that teachers could implement the curricula in classrooms with learners.

The initial reform projects, such as PSSC (Physical Science Study Curriculum), were targeted at high school students. However, it did not take long for reformers to

recognize that attempting change so late in the educational careers of learners was not having the desired impact. Robert Karplus at the University of California (Berkley) recognized this in 1959 (a year before Bruner's *The Process of Education* was published) and began to raise questions and address the issues unique to developing elementary science curricula appropriate for learners and their teachers. Elementary science education projects were funded through the 1960s. Science education reformation was now addressing the vertical K–12 science curricula. This was a significant innovation to the American education system at the time.

Despite the apparent success of the NSF curriculum projects to alter the learning and teaching of science in schools between 1957 and 1975, funding was essentially terminated in 1975. The congressional assault led by conservative Republican representatives over the upper elementary social studies curriculum Man: A Course of Study (MACOS) [1] effectively marked the end to the NSF funds for continuing the reforms, and the first modern reform wave appeared to die out. A modest number of the curricula continued in quiet use across the country, but the much needed funding to sustain teachers' professional development in science topics, the use of the curricular materials with learners, and the much needed refurbishment of kit-based materials was not available.

A later landmark event in modern education reform was the 1983 National Commission on Excellence in Education report *A Nation at Risk.* The report gained public notice and detailed the presumed poor state of education and the demoralization of

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[1] MACOS was an innovative social studies program that "broke important new ground. Students at all levels were encouraged to come to terms with a new awareness of the social divisions in the country" (Goldstein, 1992).

an ill-equipped teaching profession. The report served as a call to action to preserve the economic security of the nation's future. The national interest had become economic supremacy, which was tied to technological supremacy as opposed to the military survival needs during the early days of the Cold War. By 1990 reform in education was ready to begin anew. From the numerous studies of the 1980s, and by revisiting the events of the 1960s and 1970s reform efforts, a new approach to improving science and mathematics education was ready to be implemented—systemic reform. The nature of systemic educational reform was to approach change not only from the top down but to also approach reform at each level of the educational enterprise. The intention was to avoid the miss-steps of the past by building sustainable reform involving all of the stakeholders in the educational enterprise. National attention was also given to an "equitable" reform: One that would include all learners. Although the first reforms also sought to build equity into the instruction and experiences of learners of science, equity has proved illusive and remains a goal of today's reform efforts.

An important adjunct of the systemic approach was the development and adoption of national science educational standards, which were released in 1995. Systemic reform was an attempt to recognize the need for organizational change and accountability considered necessary to improve the educational enterprise. The push to raise learners' performances led to higher expectations for curricula and teachers' abilities to implement the curricula. The earlier reforms made clear the need for a cohesive model and structure to content within the vertical science curriculum. The *National Science Education Standards* (National Research Council, 1996), while not a curriculum, intended to provide a structure for what concepts and skills could be taught along a grade/age

continuum, how teachers should think about their instruction in science, what approaches to consider in assessment, and the overall science program design and implementation. The national standards provided a definition for inquiry and included inquiry as one of the content standards for teaching and learning science.

> The [NSF] ESR (Division of Educational System Reform) considers successful reform to result in full implementation of the six critical developments that drive systemic reform. These critical developments called "drivers" serve as the element of accountability across the 69 Systemic Initiatives (SI). The first four are "process drivers" that focus on sustainable success in changing the system's approach to the teaching and learning of mathematics and science, K–12. The remaining three drivers support driver 1, the cornerstone of achieving reform. Driver 1: Implementation of a comprehensive, standards-based curriculum and/or instructional materials that are aligned with instruction and assessment available to every student served by the system and its partners. (National Science Foundation, Retrieved April 30, 2003, from http://www.her.nsf.gov/esr/drivers)

The NSF, still the primary federal agency charged with promoting effective science education, approached systemic reform through a variety of programs: Systemic State Initiatives (1990), Urban Systemic Initiatives (1994), Rural Systemic Initiatives (1994), and Local Systemic Change initiatives (1995). It remains a critical aspect of the reform to evaluate and document the effectiveness of the reform efforts. Is the instructional inquiry present in classrooms consistent with the theoretical constructs of inquiry intended by the reform?

Purpose of the Study

The purpose of this exploratory dissertation is to present field-based research findings to describe the nature of science instruction in elementary school classrooms situated in districts that are part of the first National Science Foundation Local Systemic Change (LSC) projects. A Rhode Island LSC was chosen for the study because the project is accessible to the researcher and the Rhode Island LSC is considered representative of the LSC projects funded by the NSF.

> In 1995 the NSF funded the first LSC projects through Teacher Enhancement (TE) initiatives. The NSF TE project goals are district-level activities representing a shift in focus from the professional development of the individual teacher to that of the teacher within the context of whole school organizations. LSC projects implement exemplary instructional materials consistent with recognized standards for content and pedagogy. (National Science Foundation, Retrieved April, 2003 http://www.nsf.gov/od/lpa/news/publicat/nsf994/pages/ehr/ehr_esie1.htm)

The LSC teachers in grades K–eight participated in at least 100 hours of professional development (PD).[2] The LSC adopted exemplary NSF-endorsed science and mathematics curricula and materials for use in classrooms. A total of 72 LSC cohorts were brought into the initiative over a five-year period, with eight funded in 1995, 18 in 1996, 20 in 1997, 13 in 1998, and 13 in 1999 (Weiss, Arnold, Banilower & Soar, 2000).

LSC projects are expected to align policy and practice within the targeted districts to include:

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[2] Secondary science educators were also targeted by LSC. The number of hours of PD for secondary project participants was 130; as of 1999, the NSF increased PD hours to 130 for all teachers. (Weiss et al., 2000)

- A shared comprehensive vision of science, mathematics, and technology education;
- Active partnerships and commitments among stakeholders;
- A detailed self-study that provides a realistic assessment of the current system's strengths and needs;
- Strategic planning that incorporates mechanisms for engaging each teacher in intensive professional development activities over the course of the project; and
- A set of clear, defined, measurable outcomes for teaching, and an evaluation plan that provides ongoing feedback to the project. (Weiss et al., 2000)

Horizon Research, Inc. (HRI) of North Carolina contracted with NSF to design and coordinate the collection of cross-site program evaluation data.

The LSC in this study was awarded funds in May 1995. The Cohort One project was co-directed by a local college and an eight-district collaborative "to improve science teaching in Rhode Island elementary schools, grades K–six" (Mello, Baldasarri, & Crump, 1996). The project targeted 53 schools in eight districts. The goal of the LSC was to introduce exemplary science materials and inquiry teaching to the collaborative school districts in Rhode Island. The Program Evaluation Research Group at Lesley University was contracted by the LSC from 1995 through 2000 to collect program evaluation data using the guidelines set by HRI, Inc.

During the first year of the LSC, teachers worked with project leaders to pilot test and to select science kits. A Materials Resource Center (MRC) was established that assumed responsibility for the distribution and replenishment of the kits. Each district

partner paid an annual fee to sustain the MRC and the use of the kits. The introduction of science kits and hands-on materials was a first step toward reforming K–six science teaching in the LSC districts. Kits were adopted by the LSC Educational Collaborative to comprise the science curricula of the eight districts. Based on HRI questionnaires after the project began, most elementary teachers in the partner district schools reported using textbooks in their science instruction rather than hands-on activities.

> Teachers on a district wide scale seemed unfamiliar with inquiry learning and "exemplary science" reporting that they used lectures, pencil/paper tasks and homework assignments as major activities in presenting science concepts. (Baldasarri, 1997)

By the end of the project's funding, the Core Evaluation Reports for the LSC indicated that over 600 teachers had received professional development, which included the use of science kits. Kit Specialists conducted the science kit training with classroom teachers. Kit Specialists were K–six classroom teachers who received intensive training in the use of the kits, inquiry teaching, and leadership, and used the kits in their own classrooms. Teachers in each district were using hands-on activities in their classroom instruction and are presumably continuing to do so. Those teachers that had been using the kits for two or more years formally and informally reported becoming more comfortable with the use of the materials and an inquiry-oriented instructional approach.

Conceptual Framework

The conceptual model that has driven teacher professional enhancement in systemic reform asserts that if teachers are subjected to the proper training in inquiry-based instruction and the use of exemplary science kits three things will happen:

1. Teachers will teach science as part of the elementary curriculum consistent with the *National Science Education Standards* (National Research Council, 1996).
2. Teachers will adopt an inquiry approach to teaching science.
3. K–six students will acquire the skills necessary to become lifelong problem solvers, learn scientific content and processes, and therefore, become scientifically literate.

The larger conceptual context for Teacher Enhancement (TE) projects is the notion that teachers receive professional development within whole schools and districts rather than focusing on individual teachers.

Many LSC projects chose "kit-based science programs with an emphasis on hands-on inquiry" (Weiss et al., 2000).

This research investigates this conceptual framework and links it to the historic developments of science education from the 1960s through the 1990s, giving attention to the goal that teachers adopt an inquiry approach to teaching science. The literature relating to the introduction of inquiry as a scientific process, instructional model, and learning model during the 1960s is reviewed as a critical component in the conceptual framework.

Research Questions

This study was designed to investigate the inquiry instruction employed by elementary school teachers in K–six classrooms in an LSC project. The complex nature of teaching and the interactions between teachers, students, and the learning environment supports the use of the following qualitative research methods: interviews, observations, and document analysis.

This research study sought to answer three questions:

1. How are elementary school teachers (K–six) implementing inquiry in their teaching of science?
2. How do teachers view the use of inquiry as an instructional model in teaching K–six science?
3. What is the alignment of teachers' implementation of inquiry in the classroom with accepted definitions of inquiry?

Research Design

The nature of human discourse and interactions in classrooms does not lend itself to survey and quantitative experimental research design. This study uses a mixed-qualitative methods design. Interviews with teachers, classroom observations, and document analysis form the basis of the qualitative strategies employed to examine the research questions.

The LSC administrative personnel developed the characteristics used in this study to identify teacher participants that were "exemplary." The exemplary teachers were identified as exemplary by the LSC leadership according to the following definition:

Exemplary teachers:

1. Began in the LSC as a round-one (first year of the LSC PD) or round-two (second year of the LSC PD) participant.
2. Exhibited a commitment to science and science education PD. These individuals pursued conferences, workshops, and institutes beyond the LSC 100-hour PD requirement.

3. Assumed or exhibited leadership qualities and responsibilities within the project and/or their educational settings. Kit Specialists, in particular, served as formal teacher leaders in their capacity for providing PD to other teachers. The non-KS exemplary teachers were perceived by the project as informal leaders within their educational settings.
4. Have authored modifications to the generic kit-based curricula in order to enhance inquiry instruction and science learning.
5. Are perceived by members of the LSC as committed to the ongoing improvement of their classroom practice; that is, they are lifelong learners and reflective practitioners.

The exemplary characteristics described by the project personnel focus on learning and leadership and do not directly describe specific classroom performances. Four of the five teachers who participated in the study were Kit Specialists.

Exemplary teachers of elementary science were identified and solicited for their participation in the study. The teachers were observed teaching kit-based science lessons. Teachers identified for the study taught first through fifth grade and used NSF-endorsed science materials to teach science. The study was conducted in four public suburban schools and one urban public school situated in school districts in Rhode Island.

The case-like data for individual teachers were analyzed for holistic patterns and trends.

Chapter Summary

This chapter discussed the concerns and efforts associated with the initial post-World War II reformation of science education in elementary and secondary schools in

the United States through the 1990s. The development of a systemic approach to reform, and the *National Science Education Standards* (1996) provided the basis of science education change in public education during the 1990s. The national science education standards promoted inquiry as science process and instructional method. This exploratory study sought to examine the nature of elementary school science instruction by five exemplary classroom teachers.

Overview of the Dissertation

This chapter presented a brief overview of the purpose of the study, the research questions and design, and general discussion of the history and status of science education reform in the United States over the last 40 years. Chapter 2 of the dissertation provides a review of the literature and the thinking that has guided much of the reform in science education in the recent past and currently. Chapter 3 describes the methods used to conduct the qualitative field study of teachers' practices in elementary science. Chapter 4 presents a case-study-like approach to the analysis and findings in each classroom, while Chapter 5 presents a holistic interpretation of the data. Chapter 6 provides conclusions from the study, the implications of the study, and the limitations of the study.

Definitions

BSCS: Biological Sciences Curriculum Study is a secondary school curriculum development project (1959).

Constructivism: Constructivist epistemology questions empiricist notions of the objective nature of knowledge and knowing. Knowledge is constructed and exists in the individual.

ESS: Elementary Science Study was a set of science units for elementary and/or middle school learners developed at EDC, Inc. in Newton, MA (1962–1973).

FOSS: Full Option Science System is a K-eight science curriculum developed by Lawrence Hall Science at the University of California (Berkley).

Kit(s) and/or Kit-based science: Science units designed to facilitate inquiry in the classroom through hands-on investigations. The physical kit consists of a box of materials and instructional manuals.

Kit Specialist (KS): A Kit Specialist is an elementary science teacher-specialist with expertise in the instruction of a given kit-based science unit. KSs train other teachers in the use of the kit curricula. The position and term has grown out of the local system change projects of the mid-1990s.

LSCs: Local Systemic Change initiatives were federally funded regional and district level projects targeted at promoting change in K–12 education in mathematics and science.

MACOS: Man: A Course of Study (1965–1976) was a fourth-through-sixth-grade social studies curriculum developed at EDC, Inc., Newton, MA.

MRC: A Materials Resource Center is a regional center responsible for the housing, distribution, and replenishment of science materials that have been adopted to teach elementary and middle school science.

NAEP: The National Assessment of Educational Progress is also called the "Nation's Report Card". It is a nationally administered test (since 1969) in eight subjects to students in grades 4, 8, and 12.

NCTM: The National Council of Teachers of Mathematics, founded in 1920, is a professional organization for educators of mathematics and others interested in mathematics education.

NSES: National science education standards were first released in 1995 detailing standards for the multiple components of science education (teaching, assessment, program, content, and education system components).

NSTA: The National Science Teachers Association, founded in 1944, is a professional organization for science educators and others interested in science education.

Pedagogy: Pedagogy refers to the practice of teaching. It is the ability to convey meaningful topics to learners.

PSSC: Physical Science Study Committee (1956–1968) a high school physics unit that was one of the first funded projects in the 1950s.

Round (Cohort): A round or cohort describes entities (e.g., people, organizations) that are temporal companions.

RSI: Rural Systemic Initiatives were federally funded projects to promote change in the educational structures and resources of rural communities.

SAPA: Science: A Process Approach was an elementary science K–six curriculum developed by the Association for the Advancement of Science in 1962.

SSI: Statewide Systemic Initiatives were federally funded projects intended to promote statewide changes in education.

STC: Science and Technology for Children is a K–six science curriculum developed by the National Science Resources Center.

TE: Teacher Enhancement funds were provided by the National Science Foundation to fund systemic change initiatives that focused on improving K–12 science and mathematics teaching.

Traditional minority: A person or persons historically not considered to be a member of the dominant society (e.g., Latino/a, African Americans, American Indians, etc.).

Systemic reform: An approach to change that simultaneously addresses all of the system components.

USI: Urban Systemic Initiatives were federally funded projects to promote change in the educational structures and resources of urban communities.

Chapter 2

Literature review

This study presents a conceptual model of inquiry-based instruction to elementary school science that brings together theoretical perspectives from the following literature examined sequentially in this chapter:

- Science Education Reform Since the 1950s
- Nature of Inquiry in School Science
- Science Education and Constructivist Theory

Science Education Reform Since the 1950s

Hands-on science is not a new idea. (Karen Worth, 1990)

Connecting Then and Now

The literature of science education reform reflects several phases of reform efforts in the United States from the mid-1950s to the present (Blosser, 1990; Brandwein & Glass, 1991; Bybee, 2002; Chun, et al., 1999; Dow, 1991; Engleman (Ed.), 2001; Freundlich, 1998; Futrell, 1989; Hurd, 1986; Jackson, 1983; Matthews, 1994; National Research Council, 1996; Yager, 1992; Yee & Kirst, 1994). Bybee (1997) suggest at least three separate elementary science education reform periods consistent with NSF curriculum funding from the 1950s through the 1990s as presented in Figure 1.

Figure 1.
Title: NSF-funded Science Education Reform from the 1950s to the 1990s.

Reform Decades Post-WWII	**NSF Reform Projects**
1950s Post-Sputnik	High School (Precollege) PSSC, BSCS
1960s	Elementary/Intermediate–e.g., ESS, SCIS, SAPA, ESCP, ISCS
1970s Post-MACOS	Decline in NSF funding and a growth in elementary science textbooks (Carin & Bass, 2001)
1980s Post-Nation At Risk Triad Projects	Elementary/Middle–Insights, FOSS, SCIIS, Science Quest, NGS Kids Network NSTA's SS&C
1990s Post-2061, NSES Systemic Initiatives	Elementary/Middle/High School STC, FOSS, Insights, SEPUP SSI, RSI, USI, LSC

Each of these reformation periods or phases was consistent with curricular development efforts, and is distinct for several reasons. The earlier reforms began with secondary schools and moved down to the elementary and intermediate grades. The political concern for trained scientific manpower during the early years of the Cold War, along with the projected need of 300,000 secondary teachers by the National Manpower Council in 1953 (Rudolph, 1999), invited the attention of the government to high school education. That attention became focused on teachers already in the classroom and what could be done to effect change in "current teaching practices" (Rudolph, 1999). Science education reform in the mid-1950s gained federal support from an initially reluctant NSF for efforts targeted at high school science education.

The large number of projects resulting from the 1950s and 1960s reforms in elementary and secondary science education offered multiple approaches to content, curriculum theory, design, and development (Brandwein & Glass, 1991). The multiple approaches targeted by the differing curriculum projects provided diversity in

instructional approaches and resources. This might explain why the statistics, often viewed as evidence of the failure of these reforms (Yee & Kirst, 1994), indicate that most of the NSF-sponsored curricula "were found in no more than 10 or 12 percent" of the nation's school districts (Jackson, 1983; Griffith & Morrison, 1972). Districts and schools had more products to select from for science curricula, which included textbooks as well as the then "new" materials-based units. Even within a single project, there was considerable variety. Within Biological Sciences Curriculum Study (BSCS), multiple versions of and approaches to content were produced. This was an innovation in school science education at the time. For example, the BSCS project created a different series of biology texts for high school students. H. Bentley Glass, the first chairman of BSCS, is credited with stating:

> No one would be left with the delusion that we thought there was only one right way to organize and present the wide-ranging diversified subject matter of biology if we presented the public with three choices and said, in effect, any one of these is as good as any other. (Engleman, (ed.), 2001)

Having multiple approaches to content created options across states, districts, schools, and in classrooms, which had not been experienced before, it may also be that, as Brandwein and Glass suggest:

> The net effect of the 1960s curricular efforts on the educational ecology of the United States was the development of innovative materials that commanded assent. Of course, not all schools adopted the new programs, but the effects that their content had on the subsequent revision of other commercial textbooks led

observers to believe that the projects had, indeed, completely revised America's science curricula. (Brandwein & Glass, 1991)

After the abrupt reduction in NSF funding in the mid-1970s and subsequent discontinuing of the curriculum projects, a flurry of studies followed during the 1980s (Futrell, 1989; Jackson, 1983). These studies indicated schools had reverted to the textbook as the primary curriculum and lecture was the major form of instruction (Brandwein & Glass, 1991; Jackson, 1983). It was time for a different approach to reform. One, it was hoped, that would result in sustainable change.

Drawing on Prior Experiences

Elementary school-age children were and are capable of learning science concepts and skills by doing science. Since texts often served as the "de facto curriculum" (Kirst & Bird, 1999) in schools, there was little faith that elementary students could engage in more sophisticated ways of thinking associated with scientific enterprise. "Neither texts nor tests encourage the development of higher-level cognitive skills" (Kirst & Bird, 1999). Robert Karplus of the University of California (Berkley) began to examine science teaching in elementary schools in 1959. Karplus recognized the importance of establishing science experiences early in a child's education in order to "have a positive attitude toward science" (Karplus, 1962). Scientists sought out and benefited from the ongoing cognitive research of the time.

> While we applaud the activity of many scientists who are involved in proposing reforms for high school and college science teaching, we nevertheless believe that such improvements only reach the fraction of the student body, which is favorably disposed toward science because of earlier experience at home or in school; for

> the others it is too late. We are convinced that in this age of science and technology all citizens should have a positive attitude toward science and some understanding of scientific work. And for this an introduction to science on the intuitive level during the elementary school year is essential. (Karplus, 1962)

This was an important adjustment toward introducing science to elementary K–six grades that was consistent with the theories of emergent cognitive psychologists of the time. There were obvious challenges to the acceptance and dissemination of the actual project materials, such as publication and distribution of equipment rather than the usual textbooks. Making provisions for teachers to train with the structure of the units and the materials was another logistic concern not previously attempted with a text-based approach to teaching and learning. While reformers expected and indeed saw a need for teachers to learn science content (Andersen, 1994), it did not take long for projects to recognize the importance of the teachers' role in the process of curriculum development and implementation. The ESS and SCIS projects recruited teachers to serve on development teams, and the projects worked closely with teachers and children in schools to pilot and rework their respective units. Curriculum implementation was addressed through summer institutes—a professional development process established before WWII (Rudolph, 1999). Teachers received professional development in how to work with the innovative hands-on curricula, what the processes of inquiry were, and how to manage the learning environment and materials to support investigations. Yet issues of material organization, storage, and replenishment posed financial and spatial constraints that were beyond the control of curriculum developers, teachers, school-level administrators, and

the NSF, owing to "the ambiguities surrounding federal policy with respect to curriculum development " (Jackson, 1983).

While the materials were used or adopted across the country, there lacked a cohesiveness for what science was most worth experiencing, and the long-term sustainability for the continued development of units, storage, replenishment of materials, and ongoing teacher support in content and pedagogy became challenging. Teachers began to feel overwhelmed and under-supported in some instances, and in other instances, teachers did not see how the materials or instructional methods served learners. The concern for how to assess students' performances for measuring science learning was to become an important point of reform concern, as it is today. Scientists that were involved in the educational reforms were content specialists, and they developed the curricula in specific content and relied upon inquiry and investigations rather than text-based information for designing learners' experiences (Yee & Kirst, 1994). The reformers were building their curricula around the structure of scientific process.

The increased understanding of how children learn, a deeper appreciation for materials management and community support, and the critical role of the classroom teacher in curricular implementation (National Research Council, 2001) ultimately led to the development of a model for systemic reform. If reform as a process can be viewed in the long term, then the reform efforts of the 1950s through 1970s cannot be characterized as having succeeded or failed (Bybee, 1997). Instead, those experiences serve to inform the next phase of science education reform as the reform efforts continued toward a renewed vision of science education.

The fact that elementary school teachers had little prior experience with science themselves was one barrier to the adoption and use of the original (first-generation) kit-based units. The learning experiences of teachers with science often did not require the use of materials in the way that the projects advocated. So, even if materials were delivered to classrooms, there remained the challenge of the intended implementation of the curriculum. Yee and Kirst (1994) suggest that the "new" materials were still taught in the "old" ways and that teachers found the material too difficult for learners or themselves (Jackson, 1983). This suggests "back in the sixties and seventies many teachers were not adequately trained in the use of the curricula" (Spickler & McCreary, 1999).

> Teachers had difficulty with the content and pedagogy of new programs such as PSSC, BSCS, CHEM Study, SCIS, and ESS. Lacking educational support within their system and experiencing political criticism from outside of education, they sought security by staying with or returning to the traditional programs. (Bybee, 2002)

A goal of the current reform efforts is to provide teachers with the necessary professional development in content with the curriculum materials and to consider how to support teachers' use of curricula in the classrooms beyond the initial training experiences. This requires the development and articulation of what good science teaching is and what it looks like in the classroom.

Systemic Reform in Science Education

What worked in the post-Sputnik reform era and what did not work were assessed, and upon evaluation, a model for the systemic change of education at the state, regional, and local levels was introduced in the 1990s.

The desired impact of the earliest elementary science reformers was to make science something that children did. The reformers of the1960s fell far short in their efforts to create large-scale lasting changes in science instruction in schools. The theoretical basis of systemic education reform is one of approaching the educational components and actors simultaneously and comprehensively. Where multiple efforts across content and process had failed, the belief that reform must be comprehensive has led to efforts to reform the education system at every level—local, district, and state.

The move toward comprehensive bottom-up and top-down changes in education called for changes in instruction, performance standards for learners, and the restructuring of how the system components functioned and interacted. The systemic approach to education was a gradual shift that began with growing emphasis on issues of civil rights during the 1960s. By the 1970s the larger social issues impacting education (Tyack & Cuban, 1995) exceeded local resources and capabilities (e.g., equity and special education). Localities began to defer increasingly to state offices of education. In the 1980s the push for accountability, competencies, and testing were to stem the alleged tide of mediocrity in U.S. education. Teacher certification and preparation programs were studied. Salary increases and merit pay were discussed to retain the best and the brightest in the profession and to promote professional development. Meta-analyses of science education research was invented in the mid-1980s (Bangert-Drowns & Rudner, 1991;

Jackson, 1983; Shymansky 1984) and became a tool in the massive effort to produce reports describing what worked or might work to create the paradigmatic shift for "true" education reform. More and more, teacher performance was to be linked to learner performances by the 1990s. As states became more involved in local school issues, they wanted to hold schools and teachers accountable for the allocation of funding for improving education, resulting in high-stakes testing of children and teachers.

President George Bush met with the states' governors in 1989 in an effort to bring some sense of national clarity to the reformation of the nation's schools. From the first such education summit, Governor Clinton drafted the outline of what would become the Goals 2000: Educate America Act in 1994 during his presidency. One of the national goals, Goal 4, was the goal for science and mathematics education: "By the year 2000, U.S. students will be first in the world in science and mathematics achievement." This placed responsibility on schools to adopt exemplary programs and to create school environments that promoted teacher and student understanding of mathematics and science (Swanson, 1991; Thompson, 1994). Several projects in science were already underway that were useful to considering what Goal 4 might mean in reforming science education.

Systemic reform in science education has come to mean creating a locally or regionally based infrastructure to support and sustain quality science education after initial funding from federal offices is withdrawn. At least this was the thinking by the 1990s. That thinking was the outgrowth of the evolution of education reform begun in the 1960s and 1970s, nurtured through the 1980s, and implemented in the 1990s.

> Systemic reform is not so much a detailed prescription for improving education as a philosophy advocating reflecting, rethinking, and restructuring. Unlike reform efforts that are more limited in scope, systemic reform pervades almost every aspect of schooling. It calls for education to be re-conceptualized from the ground up, beginning with the nature of teaching and learning, educational relationships, and school-community relationships. (Thompson, 1994)

Systemic reform proposes that to sustain the change of goals in education, not just science education, federal, state, and district systems must coordinate efforts and resources. With a renewed focus on altering the way education was to function, came a renewed vision of what curricula, assessment, and instruction in science should look like.

Content standards were an important articulation of the desired results of systemic change. They represent what scientists and mathematicians along with other constituencies' value as knowledge and worth knowing. Therefore, they represent what skills and knowledge were desired for students to master. Systemic reformation in elementary science education can be viewed as a continued effort to change the way science is valued and experienced in the elementary schools in this nation. Science was to gain a foothold in the elementary school curriculum as a subject equal to language arts and mathematics. It was to have its own literacy standards, and teachers were to engage in professional development in order to teach science in a manner consistent with current notions of "best practices."

Paul Hurd, as quoted by Jackson (1983), succinctly states the nature of science instruction in the 1980s despite the reform efforts of the previous two decades: "For most teachers, science is still a noun, not a verb." However, the early reformers did create an

important and lasting innovation for curricula development (Brandwein & Glass, 1991)—the contribution of academic research scientists to elementary education at the classroom level (Dow, 1991; Goldstein, 1992; Haber-Schaim, 1998). Through "the discussion of profound issues" (Haber-Schaim, 1998), scientists sought to bring theory into classrooms rather than factual information alone (Griffith & Morrison, 1972). The important role of scientists in reforming science education has been sustained through the current reforms.

Local Systemic Change

By 1990 the NSF was ready to begin the State Systemic Initiatives (SSI). Ten million dollars were to be distributed to each member of the state-level cohorts over a five-year period in support of initiating systemic change to the education process. Other initiatives followed, such as the Urban and Rural Systemic Initiatives (USI, RSI), and finally the Local Systemic Change Initiatives (LSCs).

The 1990s LSC efforts attempted to impact the education enterprise at the district and school level. As Falk and Drayton (2000) describe from their field-based studies, district level leadership is responsible for "cultivating a culture of inquiry" in science education by articulating a clear vision and supportive environment for science teaching, science curricula, and teacher professional development in the face of required high-stakes testing.

The challenge for initiating any reform in science education was placing active science in the elementary school and convincing teachers that not only could they teach science, but also, if they let children experience science, then children would learn science concepts from doing science. The thinking behind systemic reform in science

education was that professional development for teachers in an environmental context of supportive resources would improve science education in K–12 schools. Teacher professional development has been coordinated through the LSCs and their PD has been important to sustaining an inquiry-rich approach to the implementation of the adopted curricula. The LSCs, in general, have sought to provide teachers with training in the use of the curricula as well as to strengthen their content knowledge. The curricula and how they are taught serves as an important coordinating link between systemic reform and standards-based reform as NSF TE programs begin to attempt to measure the impact of the LSCs on classroom practices and student achievement.

An important outgrowth of the reform initiatives has been Materials Resources Centers or MRCs. MRCs serve as distribution centers for science kits. Science kits are hands-on curricula adopted by many of the LSCs. The MRCs function to sustain the use of inquiry-oriented materials by LSCs. The MRCs serve collaborative schools and/or districts to defer the costs of storage, refurbishment, and distribution of the science kits, making the materials centrally managed in the LSC. MRCs interact with publishers and distributors directly while working with the various district and school LSC participants. LSC partner districts and schools share a financial commitment to sustain the costs of the MRCs and professional development for teachers. The MRCs serve as a centralizing and supportive entity in sustaining the adoption and use of inquiry-oriented elementary school science curricula.

Standards-Based Reform and the National Science Education Standards

The standards movement in education began in the late 1980s, after the April 1983 release of *A Nation at Risk* prepared by the National Commission on Excellence in

Education. The report highlighted indicators of how the United States' educational system was allegedly failing the nation. Interesting enough, the report rarely makes mention of elementary schools. However, the report does state in the recommendation section about content that

> The curriculum in the crucial eight grades leading to the high school years should be specifically designed to provide a sound base for study in those later years . . . These years should foster an enthusiasm for learning and the development of the individual's gifts and talents. (National Commission on Excellence in Education, 1983)

The traditional focus on high school and adult performance indicators was still predominantly used in framing the call for education reform. College entrance requirements, especially the Scholastic Aptitude Test or SAT (Tyack & Cuban, 1995), serve as the ultimate educational outcomes for high school seniors. There was a response to the report's recommendation for higher performance standards. High schools set more rigorous graduation requirements and businesses articulated their concerns for an educated and capable workforce.

> Each year, American corporations were spending more than $40 billion to educate their workers (a figure that included money spent on remedial education as well as other professional development). (Public Broadcast System, Retrieved May 2003, http://www.pbs.org.wgbh/pages/frontline/shows/schools/standards/bp.html)

However, the recognition that elementary education experiences formed the prior learning experiences for future learning was a pivotal acknowledgement for the impending reforms. For six years after the *A Nation at Risk* report, educators, politicians,

and the public debated over what the role of education was, how to make it equitable, and where to go in the next phase of reform (Furtell, 1989). The debates led to top-down mandates. The response was to try to control classrooms from state offices of education resulting in "more than 700 statutes stipulating what should be taught, when it should be taught, and by whom it should be taught," undermining educators (Furtell, 1989). Eventually, the dialogue matured, the legislative frenzy slowed, and hard discussions about what to teach began within various professional organizations such as the National Council of Teachers for Mathematics and the National Science Teacher's Association.

The 1989 first Education Summit in Virginia resulted in a draft of national education goals. Additional summits were convened during the 1990s and attended by educators and business leaders. During the early 1990s the federal government provided funding to support the development of standards in several subject areas. The goal was to develop specific and measurable performances for student achievement. Students, teachers, and schools could then be held accountable for meeting the standards. Today the standards movement has become synonymous with accountability and high-stakes testing (Finn, Jr. in Ravitch (ed.), 1995; Hadderman, 2000).

National science education standards are linked to the vision of a systemic, standards-based approach to education reform in general and science education in particular. The *National Science Education Standards* potentially serves as a conceptual framework for science education reform. The states are able to use the national standards as a guide for curricula design and adoption. The earlier reform projects worked from within their respective curriculum projects and used their unique perspectives and

approaches to identify what content concepts, skills, and instructional approaches were appropriate for the K–six learner.

The earlier elementary school science projects set out to capture the young learners' interest in science (Karplus & Herbert, 1967; Worth, 1990) as do the current reform materials. Studies conducted during the 1980s verified that 20 years after the adoption of the first-generation reform curricula elementary science education was still textbook driven (Kirst & Bird, 1999) and lacked learning opportunities that permitted students to gain first-hand experiences with the natural world. Despite the efforts and dissemination of the earlier NSF-funded projects in elementary science education, science was

> assigned a low priority among elementary school subjects, and is more often taught through normal recitation/discussion process than through group work, first-hand experiences, inquiry/discovery, and other methods which typify the major science curriculum projects. (Crocker, 1984)

In the spring of 1991 (National Research Council, 1996), when it was time to develop the sort of national-level consensus needed to create national science education standards, the National Academy of Science was selected (Culotta, 1994) for the task of developing national science education standards. Again, research scientists were asked to play a key role in reforming science education. As a result of their involvement during the 1950s through the 1970s, academic scientists had demonstrated the power of hands-on investigations toward facilitating students' engagement with scientific processes (Kyle, Bonnstetter, & Gadsden, 1988; Kyle, Shymansky & Alport, 1982; Shymansky, Kyle & Alport, 1983; Shymansky, 1984; Worth, 1990).

The National Research Council coordinated the development of national science education stanards and formed the National Committee on Science Education to oversee the process of standards development. There were three working groups involved in the development of national science education standards—content, teaching, and assessment. While the standards "movement" may be viewed as different from the systemic reform movement, they were not necessarily separate.

The national standards reform phase differs from previous reform visions because of its larger view of science education. Rather than focus only on curriculum and content, the *National Science Education Standards* (National Research Council, 1996) state what it is children and teachers should know and be able to do, including standards for teaching science, student assessment, science education program design and support, and teacher professional development.

National science education standards followed several earlier professional organization projects. Most notable among them was the American Association for the Advancement of Science (AAAS) Project 2061 in 1989. The decision by the National Science Teachers Association (NSTA) to call on the National Academy of Sciences to facilitate the writing of national science education standards ensured that research and academic scientists from multiple disciplines were involved, as in prior reform efforts. Other constituencies were also included in the development of the standards, including teachers. Ensuring a shared vision was an important aspect of creating and sustaining systemic reform. Because of the failure of past reform efforts, today's educators were well aware of the types of problems that arise when notions of change are not widely shared at the community level (Kirst & Bird, 1999).

The final version of the *National Science Education Standards* was completed in 1995. The standards articulated a view of science teaching and learning for K–12 classrooms that required a focus on scientific inquiry processes. The document also gave focus to the need for a comprehensive effort at all levels of the educational enterprise to change in order for the standards to be achieved. This included specific standards for federal, state, and local entities. While teachers questioned whether students could be expected to meet the new science standards and how they would teach according to the standards, it became clear that the vision for science education reform was tied to a total system change.

The *National Science Education Standards* presents as its final chapter “Science Education System Standards”. The chapter describes seven policy standards to facilitate, support, and sustain those systems that influence science education: government, the private sector, and the national organizations and societies (National Research Council, 1996). The *National Science Education Standards* is very much a document that represents what was learned from earlier attempts in formulating what the next steps will be along the reformation continuum.

The *National Science Education Standards* provides goals for school science that define a scientifically literate person (National Research Council, 1996). These goals are:

1. Experience the richness and excitement of knowing about and understanding the natural world;
2. Use appropriate scientific processes and principles in making personal decisions;
3. Engage intelligently in public discourse and debate about matters of scientific and technological concerns; and

4. Increase economic productivity through the use and skills of the scientifically literate person in their careers.

This study concerns itself with the first of the stated goals as it represents the goal most directly aligned with observable events consistent with science-related inquiry in the classroom, such as teachers, children, and the science curriculum.

National Science Education Standards Professional Development Standards

> Becoming an effective teacher is a continuous process that stretches from pre-service experiences in undergraduate years to the end of a professional career. (National Research Council, 1996)

An explicit goal of *National Science Education Standards* is to establish high levels of scientific literacy in the United States (National Research Council, 1996). If this goal is to be realized, then science teachers must also become scientifically literate. The NSF-sponsored TE programs have sought to prepare science literate teachers to teach elementary school children. In order to determine the degree of success of this reform approach and goal, it is necessary to have a definition of scientific literacy against which to evaluate the effectiveness of the reform PD approaches. Scientific literacy is defined in the NSES on several levels. The political component of the definition reads:

> Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity.

The “doing” science component of the definition is:

> Scientific literacy means that a person can set, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena.

Finally, the language component of science literacy is described in the NSES:

> Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions.

Scientific literacy as an educational goal has been a subject of debate among reformers (Oliver, Jackson, Chun, Kemp, Tippens & Rascoe). This study does not propose to enter into that debate, but accepts the articulation of scientific literacy in the national standards and acknowledges that scientific literacy, however defined, as an educational goal, ultimately serves to enrich the intellectual state of child and adult alike.

Teachers are not expected to be science experts, although the need for science knowledge and an understanding of how science is done is necessary to their professional responsibilities. Yet survey data and research (Abd-El-Khalick, 2002; Damnjanovic, 1999; Eick, 2002) suggest scientific literacy has been illusive in teacher preparation programs and traditional in-service PD experiences. Elementary school teachers historically focus their teaching on language arts and mathematics.

In 1993 Horizon, Inc. conducted a survey to measure the status of mathematics and science teaching in the United States (Weiss et al., 1999). The survey findings indicate that

1. Science and mathematics, when taught in grades one through six, received about 30 minutes per day of instructional time versus 70 minutes for reading and/or language arts.
2. "Heavy emphasis" was given to learning science facts and terms.
3. Traditional lecture/textbook-dominated instructional strategies, although there was an overall increase in hands-on activities since the 1980s.
4. Seventy percent of teachers reported feeling very well prepared to teach reading. By comparison, . . . only 28 percent felt very well qualified to teach life science; and fewer than 10 percent felt very well-qualified in the physical sciences. (Weiss et al., 1999)

In the present climate of mandated, high-stakes testing, reading remains the instructional focus of elementary school teachers. Despite the political aims to be first in the world in mathematics and science (Goals 2000) and the apparent low performances of U.S. students on international science and mathematics tests, such as TIMSS, individual states have the final word in what educational reforms, if any, they will embrace.

Teacher qualifications for teaching science vary across the United States and often are not an accurate measure of teachers' science (e.g., content) or scientific literacy (e.g., processes). National science education standards proposes not only science teaching standards, but standards for the professional development of science teaching as part of a comprehensive, systemic approach to improve science education in the United States. The standards ask providers of professional development to create "opportunities for intellectual professional growth" of teachers and not just offer professional development in the technical skills of instruction (National Research Council, 1996). According to the

standards for professional development, teachers need professional development in the content of science, knowledge and understanding of science, knowledge in how to teach science, and knowledge in how science is learned by students. Teachers are expected to be representative members of the science community in their classrooms, according to the professional development standards in the *National Science Education Standards* (1996).

To achieve effective professional development in the context of systemic science education reform and to align instruction with the science literacy goals of the *National Science Education Standards*, teacher professional development has had to undergo reform. Loucks-Horsley, Hewson, Love, and Stiles (1998) recommended that the in-service model used previously in which outside experts were brought into schools to disseminate to teachers has to be replaced with an alternative model consistent with organizational learning. Teachers as organizational members need to share in the new knowledge development rather than being recipients of externally generated knowledge. Such an approach, while consistent with creating systemic change, also crafts a response to address the specific and local needs of teachers. While having knowledge of scientific information is necessary to teaching science, it is as important for teachers to also reflect on how to encourage inquiry in the classroom. Teachers, like their learners, need to experience inquiry in order to develop a practical and theoretical sense of inquiry.

> An immersion in inquiry into science or mathematics—that is, actually learning content in new ways—can help teachers see (and feel) what new teaching practices look like in action. (Locks-Horsley et al., 1998)

Creating meaningful teacher PD requires financial support and leadership. For school districts, NSF-funded Teacher Enhancement Local Systemic Change programs became much needed, viable approaches to science education reform.

Inquiry-Based Programs, Units & Curricula

Given the attention and importance of curriculum to the study and discussion thus far, a brief overview of how certain of these materials were developed is presented. This discussion will serve as a foundation to further discussions and references elsewhere in this study. The attention to the design of curricula is also important to subsequent discussions about inquiry.

Of the original first-generation NSF-funded elementary science projects, Elementary Science Study (ESS) in 1961, Science Improvement Curriculum Study (SCIS) in 1962, and Science: A Process Approach (SAPA) in 1963, ESS proved to be the most "open discovery-based" (Karplus & Herbert, 1967). That is, ESS developers sought to present learners with materials that they could investigate in response to their questions rather than having teachers' questions as the sole driver for student action. ESS persists today as having had a "school-science-inquiry" instructional model most consistent with the structure and processes of inquiry. The units, as "each of the 56 distinct clusters of activities centering around a group of materials" (Romney & Neuendorffer, 1973) were called, did not comprise a curriculum (Karplus & Herbert, 1967). The units were stand-alone investigations that could be used across two or more grade levels and sequenced at the discretion of teachers to accommodate learners. Each of the 56 nonsequential ESS units consisted of a kit of materials and a teacher's guide. The originators of ESS encouraged teachers to let learners' interests and questions guide their investigative

experiences and use of the materials. As stated by Eleanor Duckworth in Rogers & Voelker (1970):

> There are two main characteristics, which we keep in mind. One is that children use materials themselves, individually or in small groups, often raising the questions themselves, answering them [the questions] in their own way, using the materials in ways the teacher had not anticipated, and coming to their own conclusions. . . . The other is that we try to create situations where the children are called upon to talk to each other.

Assessment ideas or strategies were provided, but there were no prescribed assessment instruments with the units.

The ESS developers tested ideas with learners in classrooms with teachers. If students did not find the topic interesting or especially motivating, it was discarded and another idea attempted for development (Rogers & Voelker, 1970; Romney interview, 1997). This form of development required creative patience and an acute ability to make meaning out of learners' actions and words. This approach to developing learning topics and materials was innovative, unusually responsive to the learner, promoted an alternative approach to assessing learners, and was time consuming.

The SCIS curriculum comprised a "hierarchy of science concepts" (Carin & Bass, 2001), a guided learning cycle approach, and provided assessments for teachers to utilize. While both ESS and SCIS and other curricula sought to promote and invest teachers and learners in inquiry, they did so from different perspectives about how inquiry ought to look and be experienced in the classroom. These post-Sputnik curriculum projects have established a legacy of elementary science material design and instructional approaches

still in use today. The reasons for the stability of unit topics as well as other aspects of unit design derive from the fact that the units' topics were interesting to learners, students interacted with the physical world, and they experienced real events in response to their questions (Stefanich, 1976).

The Nature of Inquiry in School Science

> Although SAPA, SCIS, and ESS are all activity centered, one can see that their treatment of the concept of electricity is quite different. SAPA is very structured and highly teacher directed. It emphasizes the processes used by scientists, and converges student learning towards specific behavioral objectives. ESS, on the contrary, is very student centered. After the presentation of a divergent opening question, the responsibility for learning is mostly on the individual pupil. Vocabulary is not emphasized and formal paper-and-pencil type evaluation procedures are not recommended for most units. SCIS falls between the two; the units do have objectives and the program is designed to provide children with certain concepts. There are periods of exploration and discovery interspersed by teacher-directed invention lessons. (Stefanich, 1976)

Stefanich's conclusion in the above quote, based on the comparative analysis of the treatment of electricity by ESS, SCIS, and SAPA, not only confirms the different approaches to content and teaching, but it is also an articulation of the inquiry continuum as school science inquiry has come to be accepted (National Research Council, 2000).

In this study, inquiry is described (or operationally defined) according to five essential features and their variations as indicated in Table 2–6 of *Inquiry in the National Science Education Standards: A Guide for Teaching and Learning* (National Research

Council, 2000), which describes movement and positions along the Inquiry Continuum (IC).

The continuum represents what is possible across a range of teaching and learning from kindergarten through high school.

Figure 2.

Title: Essential Features of Classroom Inquiry and Their Variations. (NRC, 2000)

Essential Feature	Variations of Classroom Inquiry			
1. Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other sources	Learner engages in question(s) provided by teacher, materials, or other source
2. Learner gives priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it	Learner is directed to collect certain data	Learner is given data and asked to analyze	Learner is given data and told how to analyze
3. Learner formulates explanations from evidence	Learner formulates explanation after summarizing evidence	Learner is guided in process of formulating explanations from evidence	Learner is given possible ways to use evidence to formulate explanation	Learner is provided with evidence
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner is directed toward areas and sources of scientific knowledge	Learner is given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner is coached in development of communication	Learner is provided broad guidelines to use, sharpen communication	Learner is given steps and procedures for communication

OPEN INQUIRY←→GUIDED INQUIRY←→DIRECTED INQUIRY

Figure 3.

Title: Inquiry Continuum (IC).

Learners and teachers are not expert scientists. The Inquiry Continuum (refer to figures 2 and 3) represents classroom experiences that enable teachers and learners to move from novice approaches of scientific processes to more expert-like processes in their shared experiences. The IC is viewed as a way to describe growth in inquiry teaching and inquiry learning over time within the horizontal and vertical structures of science curricula.

The IC can also be viewed as a sequencing of distinct beliefs about what learners need to know and can know as evidenced by both curricular design and implementation. If this is an accepted premise for further discussion, then inquiry eludes singular definition in science education despite being a generalized goal of science educators for more than four decades.

> If a single word had to be chosen to describe the goals of science educators during the 30-year period that began in the late 1950s, it would have to be inquiry.
>
> (DeBoer, 1991, in Haury, 1993)

What is inquiry in the context of elementary school-based science learning?

Inquiry can be narrowly defined as what scientists do, but then that can be mistakenly interpreted to mean just the behavioral, observable actions and products of scientists and not the intellectual experiences and creative vision for constructing meaning from the natural events of the world based on evidence.

It may also mistakenly suggest that all scientists engage in the same type or kinds of inquiry. Inquiry as a process to be learned or taught can also be argued as an "object" or "product," if there is no clear evidence of understanding of science and science processes on the part of the learner.

A review of the literature in this study has resulted in numerous definitions and descriptions of “inquiry,” “scientific inquiry,” “inquiry learning,” “inquiry teaching,” and “school-science inquiry.” Figure 4 below offers a sample of the range of descriptions.

Figure 4.

Title: Sample Definitions/Descriptions of Inquiry from the Literature, Science Curriculum Developers/Publishers.

Source	Definition and/or Description of Inquiry
National Research Council (1996) National Science Education Standards.	"Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. . . . Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations, reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations."
Haury, David L. (1993) Teaching Science Through Inquiry.	"Inquiry involves activity and skills, but the focus is on the active search for knowledge or understanding to satisfy curiosity."
Damnjanovic, Arta (1999) Attitudes Toward Inquiry-Based Teaching	"Inquiry teaching models science. In an inquiry classroom, students are allowed to experience the processes of science. (Collins, 1998; NRC, 1996; Uno, 1990)"
Otieno, Tabitha N. (1999) The Learner and Inquiry	"An inquiry approach to learning is a process whereby students explore, investigate, search for information, discover and seek solutions without much guidance from the teacher in an open classroom environment."
Jarrett, Denise. (1997) Inquiry Strategies for Science and Mathematics Learning.	"In practice, inquiry often occurs on a continuum. On one end of the continuum of inquiry might be the use of highly structured hands-on activities and "cookbook" experiments; in the middle might be guided inquiry or the use of science kits; and at the farthest end, students might be generating their own questions and investigations. A teacher's goal should be to strive for the farthest end of the continuum where students are involved in full inquiry."

Enger, Sandra K. (1998) Profiling Middle School Science Inquiry Experiences Using Student and Teacher Survey Data	"Full inquiry involves asking a question, completing an investigation, answering the question, and presenting the results to others."
Shimizu, Kinya (1997) Teacher's Emphasis on Inquiry Science and Prevailing Instructional Method.	"This study identifies the process of intelligent problem solving as the necessary condition to use the term "inquiry."
NSRC/STC pamphlet. RI LASER Middle School Curriculum Showcase, 2002.	"With STC's inquiry-centered approach, students work like real scientists do—they ask questions, make predictions, test their predictions, record and reflect on their findings, and share them with others."
FOSS Handout of curriculum information. RI-LASER Middle School Curriculum Showcase, 2002.	As an "instructional pedagogy" inquiry is described in part: "The overarching questions of science are "what's in the world?" and "how does it work?" In FOSS we break them down into discrete subquestions, as scientists must, that can be explored effectively.
Dow, Peter in Volume 2 of *Foundations*, 1999	Inquiry is an approach to learning that involves a process of exploring the natural or material world, and that leads to asking questions, making discoveries, and rigorously testing those discoveries in the search for new understanding. Inquiry, as it relates to science education, should mirror as closely as possible the enterprise of doing real science.
Dyasi, Hubert in Volume 2 of *Foundations*, 1999	Inquiry contributes to children's social development, as well as to their intellectual development. Science inquiry in school is carried out in a social context.
The New Lexicon Webster's Dictionary of the English Language (1989).	Inquiry, enquiry–*n.* the act of inquiring; a question; an investigation.

An analysis of the various definitions, descriptions, conditions, and characterizations of inquiry in relation to school-science suggests that

1. Inquiry is what students think about in relation to their actions and interactions with natural phenomena and the world.
2. Inquiry is what professional scientists do within a given field of study to add knowledge to that field of study.
3. Inquiry is an instructional approach/style that can be used by teachers in the teaching of science, and it is an approach of considerable range.
4. Inquiry is a basis for science curriculum development and design.
5. Inquiry requires the communication of ideas and is conducted in a social context.

These multiple perspectives and descriptions of inquiry, along with the historical record of school science inquiry, suggest certain beliefs about the relationships and interactions between knowledge, teachers, and learners, some of which have been consistent over the last 40 years. The intended convergence of these definitions is a scientifically literate individual (American Association for the Advancement of Science, 1990; National Research Council, 1996).

Inquiry in the Classroom

> In classrooms modeled after science as practiced, students pursue investigations of their own interests, negotiate with other collaborators as to problem and solution frames, and debate the merits of different processes for seeking solutions. Authentic science requires that students pursue their activities under the constraint that they make their actions and products accountable to themselves, their peers,

> and their teachers; that is, classrooms are organized as knowledge-producing communities in which rhetorical dimensions similar to those in science are enacted. (McGinn & Roth, 1999)

The results of the literature survey illustrate the challenges to education researchers who attempt to study and communicate about inquiry in science education settings. Inquiry as scientists experience it has been described as a goal of curriculum designers. However, scientists are experts in many different fields of study not inquiry, per se, and inquiry as an intellectual process can be applied beyond the sciences. Gunstone, Loughran, Berry, and Mulhall (1999) reject the use of the term "inquiry" for just this reason, declaring that it is too general and can be applied beyond the realm of science and science instruction. They also suggest that the term "scientific inquiry" is "restricted in meaning." They opt for the use of the expressions "scientific processes" or "processes of science" to convey the intended cognitive processes of science. Regardless of how general or specific inquiry is interpreted, inquiry is an intellectual activity associated with experiences, prior and current (Dewey, 1938; Schwab, 1962). It is not simply a procedure or a set of observable process skills for unearthing scientific truths. To limit inquiry in such a way would relegate inquiry (in the study of science) to a restatement of the scientific method.

The increased attention to inquiry as a result of education reform is revealing the complex nature of scientific thinking. McGinn and Roth (1999) point out that "an increasing number of investigations with ethnographic orientations . . . support the claim that the 'scientific method' is largely a myth and does not describe what scientists actually do." Based on the research data available, they suggest that scientific knowledge

and products are situated and result from a "nexus of interacting people, agencies, materials, instruments, individual and collective goals/interest, and the histories of all these factors."

The one commonality that emerges from the literature on inquiry is that inquiry is an intellectual activity, a cognitive state in the mind of the individual attempting to construct meaning from or in relation to a set of experiences, past and present. "Inquiry is the active search for knowledge" (Haury, 1993). This commonality has had and is having significant pedagogical implications in elementary science education. What are the differences and similarities in how inquiry is viewed in professional science and that of school science?

The literature reviewed for this study defers to individuals across fields and interests who are considered as having significant impact on how inquiry in science and science education are discussed in the education research literature and the science education standards. One such individual is Joseph Schwab, professor of natural sciences at the University of Chicago, and chair of the BSCS Teacher Preparation committee during the late 1950s. Schwab describes scientific inquiry in his work *The Teaching of Science* (1962) as being of two natures relative to scientific process and knowledge construction—"static enquiry" and "fluid enquiry." Not unlike Kuhn's (1962) "normal science," static inquiry represents investigations that seek to confirm or clarify existing, established doctrine from the unique perspective of a given scientific discipline. Investigations or inquiries that are static do not challenge the established doctrines of science. The scientific doctrines are the accepted realities or "truths" of science (Matthews, 1994). Fluid inquiry as described by Schwab (1962) is the inquiry that

challenges accepted doctrines and so has the potential to give rise to the formation of new or alternative interpretations of natural events. Where static inquiry does not question the questions being asked and investigated, fluid inquiry does. Fluid inquiry parallels intellectual revolution within a scientific paradigm (Kuhn, 1962).

> Fluid enquiry then proceeds to the invention of new conceptions and tests of them for adequacy and feasibility. Its immediate goal is not added knowledge of the subject matter, per se, but development of new principles, which will redefine that subject matter and guide a new course of effective, stable enquiries. (Schwab, 1962)

Fundamental to acknowledging differences in scientific inquiries is a belief about the nature of reality. If the role of science is to document and substantiate the existing "hidden reality" (Matthews, 1994) of the world, then science education becomes what it has been traditionally in the classroom experience: the relating of factual truths to learners who conduct prescribed activities in support of the learned facts. At best, this form of direct instruction teaches learners about inquiry. Such an approach does not present the fullness of the nature of science. Telling about inquiry and experiencing the multidimensional characteristics of inquiry are very different educational goals. When teaching about inquiry, inquiry is presented as a product of science, rather than students becoming engaged in the intellectual processes of inquiry associated with the unique nature of scientific process.

> The traditional scheme [of teaching] is, in essence, one of imposition from above and from outside. . . . Moreover, that which is taught is thought of as essentially static. It is taught as a finished product, with little regard either to the ways in

> which it was originally built up or to changes that will surely occur in the future. (Dewey, 1938)

Dewey called for a "new philosophy of experience" in conceiving instruction that places criteria upon the adoption and implementation of inquiry in school science instruction.

> Dewey urged a view of children's knowledge as fluid, flexible, generative, and unformed. By designing appropriate experiences, an educator should be able to move from children's interest and capabilities towards the more stable, definite, and structured content of organized subject matters. Thus an educator's responsibility is both to enable a child to engage in inquiry and to guide inquiry. (Roschelle, 1994)

Dewey's emphasis on continuity and interaction "within experience" suggest a pedagogy of inquiry that focuses on the state of the individual learner in a way consistent with Brunerian notions of spiraled curricular experience: "something is carried over from the earlier to the later" experiences (Dewey, 1938). Educators can benefit from knowing that while they may know "the current accepted scientific answer" or aspire to have learners "get the answer" from a set of experiences, it is what the individual learner experiences that determines the meaning or mis-meaning of an inquiry investigation. Inquiry as experience for the learner, in order that it is educative, must be carefully orchestrated to ensure that the inquiry as experienced in the science classroom is a balance of static and fluid inquiry as it is in professional scientific inquiry where each learning experience is part of a continuum of purposefully connected experiences (National Research Council, 2000). This is not inconsistent with Schwab's notions of the way in which static and fluid inquiry is necessary to the structure of science knowledge. Educators have to willingly

give up the traditional notion, as Dewey points out, that a single orchestrated experience is "the" experience that will prove meaningful in the same way for every child. Educators need to proceed based on knowledge of the learner as well as the subject at hand and view active science by children as influenced by their prior experiences, not just by formal science experiences, but by personal life experiences as well. Scientists draw on their entire experiential continuum as well when inventing science (McGinn & Roth, 1999). For educators not open to the dynamic reciprocal balance of static and fluid inquiry of science, the seemingly "false starts"—also thought of as incorrect beliefs or conclusions relative to accepted adult knowledge—of children as they begin their formal explorations into school science inquiry can create tension for teachers. David Hawkins described the process of open exploration and discovery as "messing about" in his 1965 essay "Messing About in Science" (Hawkins, 2002). Yet scientists also have false starts when they endeavor to invent science. However, their messing about becomes a part of the experience continuum within inquiry through which future experiences are impacted. A curriculum that reflects an understanding of scientific process and learners will be sensitive to the necessity of messing about and allow time and resources for its occurrence (Hawkins, 2002).

In conceiving science curriculum as a continuity of experiences, the laboratory remains an important and distinguishing experience in science learning and teaching (Schwab, 1962). Learning that is hands-on has become synonymous with laboratory investigations in the elementary science curriculum, which in turn have become synonymous with inquiry. It is in the laboratory that the learner actively engages with objects of science and the world.

[illegible]

[illegible]

[illegible]

Schwab (1962) presents a continuum of inquiry experiences in his discussion of the school laboratory. He cautions how laboratory experiences can give the "appearance, but not the reality, of enquiry."

> Three different levels of openness and permissiveness are available for such invitations to laboratory enquiry. At the simplest level, the manual can pose problems and describe ways and means by which the student can discover relations he does not already know from his books. At a second level, problems are posed by the manual, however methods as well as answers are left open. At the third level, problems, as well as answers and methods, are left open: the student is confronted with the raw phenomenon. . . . (Schwab, 1962)

Schwab suggests that the analysis of scientific literature and research become part of science education experiences in order that students understand how scientific knowledge is produced and communicated (National Research Council, 2000). Current reforms strive for students to understand and be able to apply scientific knowledge with an awareness of how such knowledge is produced (National Research Council, 1996). Students not only learn what inquiry is, but how to intellectually engage in inquiry.

Schwab's descriptions of inquiry are represented in the five essential features of classroom inquiry as they are presented in the National Research Council (2000) publication *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (Figures 2 and 3). The variations in the amount of teacher direction reflect the degree to which learners participate in full inquiry or engage in partial inquiry. If all five features are present, then the inquiry is said to be "full," but if one or more of the features is absent from the learners' experiences, then the inquiry is considered to be

"partial." The more open-ended and child-directed the inquiry, then the fuller and more complete the inquiry experience is considered to be. The more teacher-directed the experience is, the more guided the inquiry experience. The more complete and full the learner's inquiry experience is, the more engaged in fluid-like inquiry the child is, relative to the child's existing knowledge. While classroom activities do not yield new discoveries in the professional scientific community, within the child and the classroom as a science community, the knowledge is "new."

The IC is a practical tool that attempts to make inquiry compatible with the four aspects of curriculum identified by Schwab (Marsh & Willis, 1999; Schwab, 1962): (1) the elementary classroom teacher's practical knowledge that multiple approaches to teaching are necessary as well as content knowledge, (2) the social milieu of the setting, (3) the nature of the learner, and (4) the specific science subject matter being considered. Multiple instructional methods are necessary to address the range of learners and events that can impact the act of teaching.

> Science teaching should encompass a wide range of methods. Even within the realm of inquiry teaching, there is a wide spectrum of approaches. [. . .] For educators, the goal is to create a balance in terms of pedagogical approaches, student-driven investigations, and teacher direction. We weaken the possibility for successful science education reform when we draw too tight a line between inquiry and other educational methodologies. (Rankin, 1999)

Inquiry processes in the classroom, therefore, are intended to move teacher instruction and student experiences from the dogmatic rhetoric of the static to the more fluid intellectual inquiry experiences. The language of the IC features is in the form of learner

outcomes serving as indicators for assessing learner performances. What makes the National Research Council's Essential Features of Classroom Inquiry an acceptable and defining tool for school science is that the learner's actions are described in the context of the teacher 's role. For example, "[The] Learner [is] *coached* in the development of communication," and "[The] Learner [is] *guided* in the process of formulating explanations from evidence," placing emphasis on the social interactive instructional role of the teacher in relation to the desired learning outcomes. Teachers, by virtue of their instructional approach, model the processes of inquiry with learners while simultaneously engaging the learner in the inquiry process. The pedagogical challenges are in making informed decisions about how and when to scaffold learners' inquiry.

> One important sign of inquiry is the relative level of control that the students have in determining various aspects of the learning experience. In looking at these issues, we look at who controls the questions, who controls the design of the investigation, and who decides on what is an acceptable answer. (Kluger-Bell, 1999)

Teachers and students can mistakenly adopt the features of inquiry as a sequence of actions to be checked off on a science to do list, making inquiry not much more than a restatement of the scientific method. While such an approach toward inquiry might be interpreted as existing at the most constrained end of the Inquiry Continuum, such behaviors are not consistent with what it means literally to "inquire." The national standards can inadvertently promote this thinking if the standards are interpreted as a manual for science instruction rather than as a guide that denotes possible best practices for teachers and districts to incorporate or adopt. The intellectual aspects of inquiry need

to be present for purposeful, meaningful inquiry to be experienced. Another concern is that teachers approach science teaching as an intellectually unstructured process in an effort to achieve full inquiry. Teachers can mistakenly believe that the learner simply "handles" objects and whatever conclusion learners come to about those experiences is acceptable and should remain unchallenged or tested beyond the child's current experiences. They may fail to realize that their role in a full-inquiry learning environment is to facilitate questioning and the development of evidence-based knowledge.

Elementary education has the special challenge of providing prior experiences for future science learning and understanding. This should not translate into preparing learners for the next grade level. What it does mean is that students need opportunities to learn science processes and begin to think about what evidence is. Scientific inquiry is a way of approaching the world that has to be learned and appreciated. Students' novice explorations are a form of practice with inquiry, content concepts, and fundamental process skills. Therefore, it may be inappropriate to view the most self-directed end of the inquiry continuum as the absolute outcome at/for each grade level. Students need to be free to explore the world and to be guided through a shared process of making meaning of their explorations.

This study seeks to observe and listen to classroom science instruction, and "through listening, try to develop understanding of inquiry-based science" as it emerges and is experienced in classrooms (Boyle & Skopp, 1998).

Constructivism in Science Education

> I don't know what's the matter with people: they don't learn by understanding; they learn by some other way—by rote, or something. Their knowledge is so fragile! (Feynman, 1985)

Richard Feynman's quote comes from an event in his mechanical drawing class while attending MIT. He relates the surprise at his fellow students who discovered that the tangent at the point on their French curves is horizontal or zero. The French curve is based on differential calculus, which by that time all of the students had taken in their mathematical courses. Feynman was surprised that until that moment of "discovery," the students had not made the connection between their "knowledge of mathematics" and the French curve. As Feynman put it, "They didn't even know what they 'knew'" (1985). This story and stories like it illustrate the challenges of knowing and knowledge. Students often seek to comply with the requirements of the immediate instructional setting. Unless there is an intervening experience that mediates the instructional setting to create opportunities for discovering connections to alternative problems and events, the learner and teacher may not be fully aware of what is known and how it is known.

"Constructivism is not a new concept" (Hanley, 1994; von Glaserfeld, 1993). The recent adoption and use of constructivist epistemology as it relates to science education is in evidence in the science education and inquiry literature base (e.g., the Exploratorium Institute for Inquiry, Inquiry Education Resources online articles). Shymansky and Kyle (1992) describe how "empiricist philosophy", as "an idea that knowledge is out there in the world and has only to be accessed by the senses in order to be transferred to the learner", has influenced teaching. Constructivist epistemology questions empiricist

notions of the objective nature of knowledge and knowing. A fundamental tenet of constructivism is the "subjectivity of observation" (Shymansky & Kyle, 1992). Knowledge is constructed and exists in the individual. Constructivist thinking directed aspects of the early science curriculum reform efforts. For example, developers of the Elementary Science Study (ESS) found that it made no sense to select content and construct meaningful activities without the learner—that is, without being child-centered. Only by including the nature of the learner, and therefore the learners' experiences, was it possible to conceptualize a set of meaningful learning experiences Interviews with ESS unit developers (conducted in 1997 and 1998) describe the iterative process of using content and process with learners:

> [We] got an idea and we took it to school . . . if it didn't work, then we threw it away. If the kids weren't interested, we said, "Well, that's too bad." We thought it would be interesting, but it wasn't. (Churchill interview, 1997)

Curriculum is for students and teachers, and "Teachers' roles mediate the learning of students" (Tobin & Tippins, 1993). Teachers are engaged in the process of making sense of the learning environment and actively constructing pedagogical meaning (Shymansky & Kyle, 1992). David Haury (1993) summarizes the relationship between the teachers' instructional goals for creating a learning environment conducive to inquiry processes and constructivism as a pedagogical referent for learning:

> From a pedagogical perspective, inquiry-oriented teaching is often contrasted with more traditional expository methods and reflects the constructivist model of learning, often referred to as active learning, so strongly held among science educators today. According to constructivist models, learning is the result of

> ongoing changes in our mental frameworks as we attempt to make meaning out of our experiences (Osborne & Freyberg, 1985, in Haury). In classrooms where students are encouraged to make meaning, they are generally involved in "developing and restructuring [their] knowledge schemes through experiences with phenomena, through exploratory talk and teacher intervention" (Driver, 1989, in Haury). Indeed, research findings indicate that "students are likely to begin to understand the natural world if they work directly with natural phenomena, using their senses to observe and using instruments to extend the power of their senses." (National Science Board, 1991, in Haury, 1993)

An alleged failure of past curriculum reform has been that only the curricula were reformed. Teachers' beliefs about content and/or instruction were unaffected by the introduction of the curricula. However, this generalized interpretation of the historical evidence fails to acknowledge what is now known about how difficult it is to change the firmly held beliefs of teachers and the important and complex nature of personally held and socially viable knowledge and how schools function. As with learners, PD reform can only invite the transformation of cognitive structures (Brooks and Brooks, 1993). Teacher enhancement reform has been directed at altering teachers' thinking and, therefore, their actions in the instructional interpretation of curricula designed to promote full and complete inquiry. It is toward this end that PD reform is designed to create alternative learning experiences as referent experiences for teachers to draw on in the classroom (Tobin & Tippens, 1993). Essentially, PD reform invokes the tenets of constructivism with the intention of transforming teachers' thinking, and eventually, the transformation of their practice. The University of Massachusetts Physics Education

Research Group (UMPERG) (Retrieved 2002) suggests the following pedagogical connections between constructivism and the practical methods of science instruction:

Figure 5.
Title: Constructivism and Pedagogy. (UMPERG, retrieved 2002)

Premises of constructivism as an epistemology	**Premises rephrased for pedagogical purposes**
Knowledge is constructed, not transmitted	Students come into our classrooms with an established world view
Prior knowledge impacts the learning process	Even as it evolves, students' world views filter all experiences and affect their interpretation of observations
Initial understanding is local, not global	Students are emotionally attached to their world views and will not give up their world views easily.
Building useful knowledge structures requires effortful and purposeful activity	Challenging, revising, and restructuring one's world view requires much effort.

Constructivism is a theory about knowledge and learning rather than a theory about teaching (Brooks & Brooks, 1993). It is not surprising, therefore, to find that PD reform in science education has merged notions of science teaching with the tenets of constructivism. The essential components of constructivist pedagogy are:

- Provide an interesting invitation to learn
- Learners engage in exploration and discovery
- Learners propose explanations
- Learners take action
- Learners apply/demonstrate knowledge. (Loucks-Horsley in Jakubowski, 1993).

Examples of teaching materials and instructional models that promote scientific inquiry using constructivist orientation have been described in Loucks-Horsley et al. (1990) and include models and resources from Education Development Center, Inc., BSCS, Lawrence Hall of Science, and National Science Resource Center.

Chapter Summary

This chapter related the influences of prior science education efforts to present reform efforts to illustrate how one reform phase has set the groundwork for the next. Systemic reform is a process that has been described in the literature as requiring many parts of the educational enterprise to work together to affect desired changes. Prior reform efforts have been viewed as being separate in purpose and disjointed. These efforts, in fact, brought variety and diversity to the products and approaches of current reform, allowing the individual projects to demonstrate the need for reformers to respond to the milieu of schools and the needs of teachers. The nature of inquiry as part of the curricula that were produced in the post-Sputnik years ultimately represented a range of instructional models/approaches, some of which seem counter to a complete and full inquiry enterprise. Despite these variations and struggles to infuse science into elementary education, inquiry as an instructional goal and learning process gained value and a foothold in science education. Inquiry has remained the focus of science education reformation since the 1950s in the United States.

Inquiry has been defined in this study in terms of student learning and pedagogical practices consistent with the epistemology of constructivism. Relying on the influences of John Dewey and Joseph Schwab, this study describes inquiry in science as an intellectual activity involving investigative experiences and perceptions of the natural world. Inquiry requires that the construction of knowledge be based on the interpretation of evidence from meaningful experiences (e.g., science investigations) of interest to the investigator. Inquiry in the educational setting maintains the same standards for evidence;

however, inquiry is a skill being learned and practiced, and as such, inquiry in the context of school science requires time and guidance to master.

The Inquiry Continuum represents the varying degrees of inquiry in which teachers and learners engage in the classroom. It describes the desired outcomes for science literacy across the K–12 grades. It also suggests to teachers that multiple instructional models are needed in order to accommodate students' growth over time. The long-term goal of inquiry experiences is for learners to become self-directed and scientifically literate, knowing the processes of science, how science is constructed, and attaining conceptual understanding of identified scientific principles and theories.

Inquiry as a constructivist-oriented instructional strategy has also required the reform of PD. Constructivist-oriented PD has relied on transforming teachers' practices by immersing teachers in inquiry experiences with the materials they will use with learners.

Chapter 3

Overview of the Research Design

This study investigates the implementation of inquiry processes in classrooms using NSF-endorsed, kit-based curricula. Interviews, surveys, classroom observations, and document review were the primary research methods used in the study. Classroom observations and interviews with classroom teachers were performed and resulted in 179 pages of descriptive and transcribed data. A participant survey was administered, and photographic images of the settings, copied samples of students' work, and teacher manuals were collected for analysis. These materials were used to develop a case-based approach to the analysis of the individual classroom setting. The individual cases were analyzed for patterns and themes. The case data were re-examined and analyzed in whole for patterns and themes across settings.

The methods used to identify study participants and to develop protocols are discussed in this chapter.

Methodology and Rationale

The research question asked in this study—How are elementary teachers implementing inquiry in their science teaching?—was addressed using qualitative methods. "Qualitative research is itself a field of inquiry" (Denzin and Lincoln, 1998) suited to the investigation of complex phenomena.

> Qualitative research is multimethod in focus, involving an interpretive, naturalistic approach to its subject matter. This means that qualitative researchers study things in their natural setting, attempting to make sense of, or interpret,

> phenomena in terms of the meanings people bring to them. Qualitative research involves the studied use and collection of a variety of empirical materials—case study, personal experience, introspective, life story, interview, observational, historical, interact ional, and visual texts—that describe routine and problematic moments and meanings in individuals' lives. (Denzin & Lincoln, 1998)

The inductive approaches of qualitative research afford the researcher multiple views from which to examine natural settings and events and "build toward general patterns" (Patton, 1990). Qualitative research methods have an established history in the field of educational studies (Denzin & Lincoln, 1998). Schools are complex settings, and teaching is a complex social process (Shymansky & Kyle, 1992). Interview and observation enable the researcher to gain direct access to the empirical processes of instructional discourse. This study sought to examine what teaching and learning look like where scientific inquiry is purported to be occurring in collaborative school districts of an LSC located in Rhode Island.

The research questions this study sought to address were:

1. How are elementary school teachers (K–six) implementing inquiry in their teaching of science?
2. How do teachers view the use of inquiry as an instructional model in teaching K–six science?
3. What is the alignment of teachers' implementation of inquiry in the classroom with accepted definitions of inquiry?

Once the research questions had been formulated, the process of participant identification was initiated.

Participant Identification

Meeting with LSC Personnel

In the spring of 2002 the researcher met with co-principal investigators (co-PIs) of the LSC to present the dissertation prospectus and research questions. The meeting with the principal investigators was necessary to the research design for several reasons. First, the meeting established formal entry and access to the LSC and LSC-teachers situated in the collaborative districts. Secondly, the meeting was used to assure the principal investigators that the study was not an evaluation of the LSC, but a separate exploration of the status of elementary school science instruction in an established first-round LSC. Given the role of the researcher as Lead Program Evaluator to the LSC during the funding period of the project, it was consistent with established professional evaluation ethics (American Evaluation Association, 1995) and Lesley University's "Statement of Policies and Procedures Governing the use of Human Subjects in Research" (2000–2001) to discuss the boundaries between utilizing information about the project that are publicly available and the need to ensure anonymity of the research subjects.

Subsequent to meeting with the co-PIs, administrative personnel in the project who worked closely with teachers were identified and contacted. The purpose of the meeting with project staff was to introduce them to the basic research questions and design and discuss the project's criteria for qualities that characterized exemplary LSC teachers. Once the qualities of an exemplary teacher had been developed, the project staff provided the researcher with a list of 28 exemplary classroom teachers and Kit Specialists who were situated in the LSC districts in Rhode Island.

Contacting Teachers

Letters and electronic mail were sent to all 28 teachers. Five teachers responded and expressed an interest in participating in the field study. The five respondents were contacted by telephone to discuss the nature of the study and the intended research methods to conduct the study. During the telephone discussions, teachers were told that the nature of the study was to look at the use of kits in elementary school science in a first-round LSC. Teachers were made aware that scientific inquiry processes implemented with kit-based materials was an important aspect of the study's focus. It was communicated to participants that the study was descriptive and exploratory in nature, and the research effort was not an evaluation of their instruction.

Once the five respondents agreed to participate in the study, a copy of the Informed Consent form and the Teacher Background Survey were sent by electronic mail to the tentative participants. They were asked to review the attached documents and reply by electronic mail their intention to participate in the study. Respondents were told that upon receipt of their informed consent, the researcher would send a letter of introduction describing the nature of the study and their involvement to their building principals. Finally, a meeting was arranged with each participant to conduct a first interview. At the time of the interview, each participant received and signed two copies of the Informed Consent. Teachers were asked to sign both copies and return one signed form to the researcher as a formal commitment to continue in the study.

Using this process, five exemplary LSC teachers, located in four different but representative LSC districts in Rhode Island, were identified. All five teachers completed the field study. To assure the anonymity of the participants, a pseudonym is used for

them and their schools. Four of the teachers taught in public elementary schools, and one teacher taught in a public middle school. Two teachers were situated in the same school district. The observed grade levels ranged from first through fifth grade, and one teacher taught grades one through three in a multiage classroom. Four teachers taught using the Full Option Science System (FOSS) kit-curricula developed by Lawrence Hall of Science, University of California (Berkley), and one teacher taught from the Science and Technology for Children (STC) kit developed by National Science Resources Center.

Teachers' Professional Background and School Profiles

Each research participant completed a professional background survey. The three-part survey provided general information about the participants' teaching experience, their academic backgrounds, and their LSC professional development and experience with science kits. The survey was originally sent to teachers by electronic mail. The survey information was used to prepare a profile of each teacher. The complete professional background survey is provided in Appendix A.

Current quantitative school profile information was retrieved from the Information Works Web page. Information Works is supported by the Rhode Island Department of Education and the National Center on Public Education at the University of Rhode Island. School profiles and performance information over the last four years has been collected, analyzed, and maintained in accordance with the "Rhode Island school accountability initiative" by Information Works. (Rhode Island Department of Education & the National Center for Public Education, 2002). The school profile data was used along with the teacher survey information to familiarize the researcher with the field

settings in the study. Additional school information was obtained during observation visits.

Pre-observation Interviews

A semistructured, three-part interview protocol was prepared to discuss teachers' understandings and beliefs about science and science inquiry. The complete interview protocol is provided in Appendix B. The pre-observation interviews with participants were held at different times and various locations. Two teachers were interviewed in early July 2002 at a professional development workshop on a nearby college campus. Two teachers were interviewed in early September 2002 in their classrooms, and one interview was done in early October 2002 on the telephone. All of the first interviews with teachers were conducted in person and prior to conducting classroom observations, with the exception of one teacher. That first interview was conducted by telephone 48 hours after the first classroom observation in the teacher's classroom due to difficulty with scheduling. The interviews took approximately 30 to 40 minutes each.

Teachers were asked to describe what science inquiry looks like during an elementary school science lesson in their classrooms. The second part of the interview asked teachers to describe their perceptions of scientific inquiry and the nature of science. The third part of the interview asked teachers to describe what type of professional development experiences prepared them for teaching science using an inquiry approach.

Classroom Observations

Descriptive observation was used to document actual learning and teaching events during the teaching of an instructional unit in science. Teachers were asked to schedule

eight classroom observations over the course of their planned kit-based science units. The science kits are distributed to area schools through the Rhode Island Science Materials Resource Center. Observations were conducted either weekly or twice weekly over a four-month period from September to December. Eight observations in each classroom were originally scheduled. In two classrooms, less than eight lessons were observed; one classroom was visited six times and another classroom was observed seven times over the course of the unit. In the classroom in which seven observations were completed, the re-scheduling of school-wide curriculum events impacted the intended observations. The science unit was interrupted in order to teach a social studies unit. Upon completion of the social studies unit, the science unit resumed. In the classroom in which six observations were completed, the school's rotating six-day schedule limited the researcher's accessibility to the site.

Figure 6.
Title: Observation Timeline by Monthly Dates

Schools	No. Observations*	September	October	November	December
Hilltop ES	6		3, 10, 17	7, 14, 18	
West Haven ES	7	24	1, 8, 29		2, 3, 10
Bayside ES	9	19, 26	3, 10, 17, 24, 31	7, 14	
Pleasant View ES	8	16, 24	1, 8, 22, 29[t]	12, 19	
Turtle Lake MS	8	19, 26, 30	7, 21,31	4, 7	

***Total number of observations equals 38. ES=Elementary School. MS=Middle School.**

Observation notes were captured using a computer as well as hand-written notes in a notebook. Where possible and appropriate, the researcher also used a digital camera to collect image data of the physical setting and to document students' actual engagement with materials and students' products. The image data was used to provide a visual

(empirical description) record for the researcher and teachers. No full-face photographs were taken of adults or children in accordance with child protection laws and Lesley University's "Human Subjects in Research" (2002). Digital photographs were made available to four of the five teachers in the form of a digital movie burned onto a compact disk (CD). Three teachers previewed the photographs or movies during the post-observation interviews, after completing the formal field visits, or at the last-site visit. The teachers made suggestions to make the movies useful to their classroom instruction, professional development, or to share with parents and colleagues. Arrangements were made with teachers who requested that children make vocal contributions (narrations and singing) to the movies to ensure that learners contributed to the research artifact. The researcher sent one movie via electronic mail and a second time on a CD to the fourth teacher because the post-observation interview was done on the telephone. The electronic e-mail with the iMovie attached was sent prior to the interview for viewing by the teacher. However, the teacher was not able to preview the iMovie, and the CD was mailed. In another classroom, the researcher believed it inappropriate to take photographs as the process overly distracted students.

Where possible, teachers' lesson goals were provided to the researcher before an observation through electronic mail or upon arrival to the classroom. After an observation was completed, providing teachers' schedules permitted, teachers were asked to briefly state their satisfaction with the lesson in relation to their goals. This was not possible all of the time for all teachers and remained a semistructured exchange throughout the field study. However, periodic impromptu discussions with teachers during observations were

held to ensure that researcher interpretations of events were consistent with actual classroom events.

Students' actions and discussions were observed and recorded throughout the study in each classroom. The researcher moved as much as possible and appropriate to observe individual students and small groups of students. All of the students were observed in each classroom over the course of this study. The data were reviewed to determine the extent to which students were actively engaged in the learning of science within a given lesson as well as over the course of the unit. The students observed in this study were actively engaged or involved in the science learning events and activities during the respective units of instruction.

Post-observation Interviews

Post-observation or closing interviews were held with each participant after completing the scheduled classroom observations. The interviews were conducted between December 2002 and January 2003. Individual teachers were asked to identify a time and date to meet or talk on the telephone. Three teachers were interviewed during the school day in their classrooms during their free or planning period. These interviews averaged 35 minutes in length. Two teachers were interviewed by telephone in the evening for a similar period of time. The complete post-observation interview protocol is in Appendix C.

The post-observation interviews afforded the researcher an opportunity to formally share with teachers the observation data that had been collected and general impressions, including any image data. Those teachers interviewed by telephone were sent the researcher's observation notes by electronic mail. The three other teachers who

were interviewed face-to-face were given hard copies of the data at the time of the interviews. An interview protocol was developed to focus the participants on reflecting on their teaching and impressions of the curriculum unit each taught. Given the difference in setting, grades, and content taught, the interviews remained semistructured discussions about what happened or didn't happen during the course of the unit.

Teachers generally were interested in getting factual feedback, as well as interpretive feedback, for example, how to move toward open inquiry in science teaching. Teachers were informed of the analysis process and given a time frame for when a more extensive data based discussion about the findings from this study could be scheduled.

Document Review

This section of the chapter describes documents that served to provide background information about the LSC and the materials that the LSC districts adopted for their science programs, such as teacher manuals. Student artifacts were also examined in relation to teacher's instructional goals.

Enhancing Teacher Performance

In Rhode Island, where the LSC in this study was located, science is not tested by state mandate at any grade, although since 1996, state science education frameworks, based on the national reform document AAAS 2061, were developed. The National Assessment of Educational Progress (NAEP) serves as the only consistent indicator of students' science ability over time. The state was a member of the NSF SSI round one cohort group, but lost its funding in 1994 (Corcoran, Shields & Zucker, 1998; Zurer, 1994). Without specific state-level leadership, guidelines, and processes for the

reformation of science education, school districts and community partners have been responsible for creating change and awareness in science education locally, using only the State Science Frameworks and the NSES to guide them. Ultimately, what drives elementary science education reform in the state's 36 districts is how science is valued within the context of a connected, comprehensive approach to the elementary school curriculum within a given classroom, school, or district. This usually means science supports the development of language arts. Therefore, federally supported Teacher Enhancement LSC projects have served a vital role in creating and sustaining teacher PD in science and systemic changes in science education in Rhode Island.

Elementary teacher qualifications in Rhode Island require a bachelor's degree and the completion of an approved program of study that includes a methods course in science teaching. The elementary methods courses historically vary across the higher education degree-granting institutions in the state. Each institution requires a different number of laboratory-based science courses. For example, at one institution, two laboratory science courses are required: one in biology and the other in physical science. At another institution, while two science courses are required in the elementary education program of study, only one of those courses is required to be a laboratory science course.

Finally, there are no state-level incentives for in-service elementary school teachers to pursue science and/or science education PD in Rhode Island. Rhode Island communities maintain a strong tradition of local control over school curriculum, which ultimately mediates teachers' choices when seeking PD. Through the program evaluation process of the LSC, field-based information was obtained on existing teacher preparation and approaches to elementary science education in eight of the state's nearly 40 districts.

During the academic year 1995–1996, the first year of the LSC and before PD programs were completed, two hundred teachers in the LSC school districts responded to HRI, Inc. questionnaires of which about 10%

> reported that they were educated in science and science teaching. In addition, a majority of teachers in project districts reported teaching science from the textbook as opposed to using hands-on activities. Teachers on a district wide scale seemed unfamiliar with inquiry learning and "exemplary science," reporting that they used lectures, pencil/paper tasks and homework assignments as major activities in presenting science concepts. (Mello et al., 1996)

The quality of science instruction is best obtained from observing classroom instruction. Observation also documents the capacity of the school setting to support science instruction.

The PD environment of classroom teachers who were observed in this study has been characterized in part through the Core Evaluation Reports prepared by the Program Evaluation and Research Group (PERG) of Lesley University (1995–2000). The program evaluation reports prepared by PERG over the funding cycle of the LSC capture aspects of the PD experiences of teachers within the project districts.

References to the evaluation data in this study are limited by the intentions for the data collected and the collection protocols used. However, certain findings were useful in understanding the study setting and the PD structure developed for facilitating exemplary science teaching as defined by the LSC.

LSC PD was structured to embrace aspects of professional development reflected by research literature (Loucks-Horsley et al, 1989; Loucks-Horsley et al., 1998). LSC

administrators sought to design a program that allowed experienced, in-service teachers to (1) gain knowledge about science and science learning/teaching; (2) develop classroom strategies for incorporating that knowledge into their teaching in a supportive learning environment, and; (3) have knowledgeable, exemplary peers as well as outside experts serve as professional developers (Loucks-Horsley et al, 1989; Loucks-Horsley et al., 1998).

Kit Specialists

Four of the five teachers in this study were Kit Specialists (KSs). KSs are highly trained classroom teachers that serve as professional developers of other teachers. Teachers either volunteered or were actively recruited to become KSs by LSC personnel. KSs function as lead teachers responsible for conducting workshops at LSC institutes to train teachers in the use of the kits. Below is a list of some of the KSs primary responsibilities:

- Participate in professional development opportunities.
- Lead professional development activities for others.
- Pilot new kits/assist with development of kits/develop new kits.
- Develop kit extensions.
- Develop performance assessments.
- Introduce/create kit-related Web sites.
- Presentations/community outreach. (Baldasarri, 1997)

The LSC supported KSs with retreats that served to provide a deeper understanding of the kits, inquiry, performance assessment, presentation skills, and to develop and nurture an "atmosphere of professionalism" (Baldasarri, 1997) and community. The KSs'

responsibilities bear a strong resemblance to the characteristics of an "exemplary teacher" as defined for the purposes of this study (See Chapter 1).

Science Kits

Kits, usually three to four per grade level, comprise the official, intended science curriculum to be implemented by teachers in classrooms with learners. Each kit, for the purposes of this study, is an instructional unit. The physical kit consists of a box, or boxes, containing the necessary teacher manual, student handbooks, MRC inventory list of consumable and nonconsumable supplies, teacher's user logs, and supplemental project-developed learner assessments, along with the actual materials for conducting investigations. The kits are supplied with sufficient materials for a classroom of up to 30 students. The kits are inventoried upon receipt from the MRC and again after classroom use before being returned to the MRC.

Four teachers in the study taught using the Full Option Science System (FOSS) kits. The FOSS kits comprise a comprehensive science program that addresses four areas of science content. The kits taught during the study represent each of those areas: physical science, life science, Earth materials, and scientific reasoning and technology. One teacher taught using a Science and Technology for Children (STC) kit.

Figure 7.
Title: NSF-Endorsed Kits Taught.

Teacher	Grade(s)	Content	Kit
Onna	1, ESL	Physical Science	Balance and Motion, FOSS
Allison	2	Life	Insects, FOSS
Natalie	Multiage—1,2,3	Earth Materials	Water, FOSS
Rachel	4	Physics	Electric Circuits, STC
Tanya	5	Scientific Reasoning and Technology	Models and Design, FOSS

The curriculum materials for each kit were reviewed to inform the researcher what intended science content was to be taught in each classroom and to become familiar with the unit structures. Reviewing the curricula allowed the researcher to document any modifications to the kits by the teacher or LSC, such as lesson extensions or supplemental assessments.

A goal of this study was to document the range of instruction used by experienced teachers in elementary school science. It was an assumption in this research that the NSF-endorsed, NSES-based science kits represented elementary school science curricula that promote inquiry as a learning outcome for students and an instructional strategy for teachers (National Research Council, 2000). Within a given kit, the unit was designed to promote both facets of inquiry. Therefore it was important to the research to allow sufficient time and opportunity to document evidence of both aspects of inquiry, if present, by observing as much of a given unit as possible.

Each kit was also designed with the purpose of targeting specific science concepts and processes within a predetermined developmental range. However, it was anticipated that teachers' perceptions and understandings of children, science, inquiry, LSC professional development, and instructional experiences with the kits would impact how kits were actually implemented with learners. Thus, while it was assumed that some lessons might be delivered as "prescribed" by the teachers' manuals, the assumption was made that teachers would make interpretive adaptations to kit lessons as they deemed necessary and appropriate. Therefore, it was an intention of the study to look at what teachers said they would do in relation to actual events.

The FOSS units for the early childhood classrooms (grades K–two) were developed for learners to work in groups as individuals. FOSS developers have designed the units for middle and upper elementary grades (three through six) to be executed in collaborative groups encouraging individual learners to contribute to the investigative process.

Student Artifacts

An important aspect of the study was to look for and document the essential features of the science inquiry process in teaching and learning. It was assumed student products and activities would provide evidence of inquiry processes. In four of the five classrooms, students maintained science journals over the course of the unit. Sample copies or photographs of student journal entries were examined for evidence of inquiry-related processes and skills. In the one classroom where students did not maintain a science journal, the one physical artifact they produced over the course of the study was a picture and a descriptive sentence of what a scientist is or does. Since photographs were not taken in this classroom, descriptive observation was employed to document learners' products.

Chapter Summary

This chapter presented an overview of the qualitative methods employed in this study to address the research question, How are elementary teachers implementing inquiry in their science teaching? Multiple methods were used over the course of the study, including 38 classroom observations of teachers and students, pre-observation and post-observation interviews with teachers, review of science curricula, and student

artifacts generated. Chapters 4 and 5 of this study present the analysis and findings from the data.

Chapter 4

Analyses and Findings

This chapter of the dissertation discusses analysis of the data and the findings from each classroom using a case study-like approach. Narrative alone does not adequately meet the criteria of a case study. It is acceptable practice in qualitative research to utilize mixed methods and measures to ensure a contextual description of the field study. Therefore, this study also accounts for the frequency and nature of interactions observed in the study from descriptive notes taken during classroom sessions.

The coding schemes used in the analysis of the observation data are presented using diagrams or conceptual maps. Data that lends itself to quantification is tabulated as percentages or numerical totals. The data is presented in support of the assertions of the findings.

Data Management and Analysis of Classroom Observations

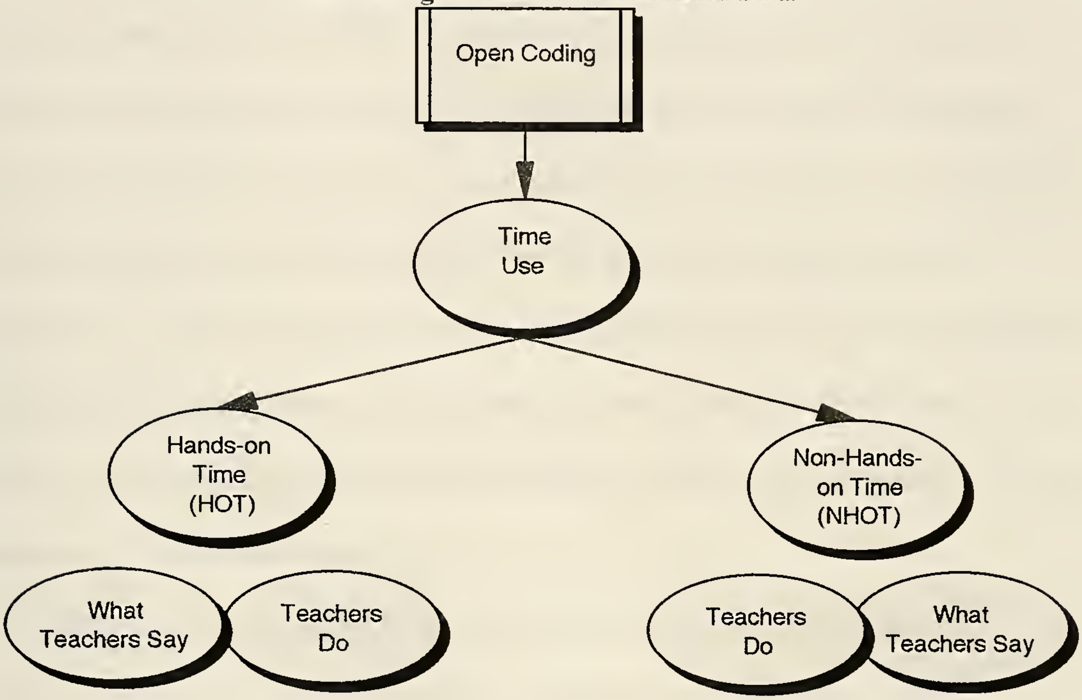
Between six and nine classroom observations during science instruction were made in each of the respective classrooms. The observation data was analyzed first by editing, correcting, typing, and transcribing raw field notes. This initial immersion afforded the researcher an opportunity to re-engage the data, review the events, and capture descriptions shortly after conducting the fieldwork. Following the initial management of the data, an open coding of the data furthered the processing of the data. This required multiple reviews of the data—no less than five readings—and the identification of principle data categories as a result of recurrent themes or patterns. The

observation notes were then read again to determine if the data continued to support these tentative preliminary assertions.

A review of the data during the open coding phase of the analysis yielded the category of time use in response to the question, How is science instructional time used? The data from each case study was sorted according to how time was used by way of a polar grouping: Hands-on Time (HOT) and Nonhands-on Time (NHOT). Once the data was sorted in this way, it was possible to code the data into the descriptive subcategories of What Teachers Say and What Teachers Do within a time-use category. While these categories may appear arbitrarily defined, it is common to qualitative research and evaluation to look at what actors say and do according to the context of the setting. In classrooms, time is often used to define what actions will occur, such as when and how much time was dedicated to teaching science. Since all of the teachers teach science curriculums that promote hands-on activities, the amount of instructional time dedicated to this aspect of implementing the curricula was appropriate to describe if the kits were used in a manner consistent with their intent and design. By the converse, it became appropriate to ask what was being done and said during the nonhands-on periods of a science lesson in order to better understand how inquiry was manifested when materials usage was not the immediate focus of activity.

This approach to data management and analysis is thought to be consistent with what Huberman and Miles (1998, in Denzin & Lincoln) refer to as “data reduction,” “data display,” and “conclusion drawing and verification.”

Figure 8.
Title: Coding of Classroom Observation Data.



Each case story was then analyzed further to identify codes for what teachers said and did. This further processing of the data ultimately generated descriptive codes representing teachers' actions and vocalizations during science class time. Essential to issues of validity and reliability was that physical events and dialogue were captured as accurately as possible. Toward this end, and to the extent possible, verbatim exchanges and discourse were captured as well as photographic images in four out of the five classrooms. The image data was reviewed in association with the dialogue and narrative descriptions of the observation data to ensure an accurate record in support of initial assertions and interpretations of the data. For example, a review of what students did with materials can be associated with dialogue in the classroom during both HOT and NHOT discussions. The image data from the four classrooms where it was obtained was then arranged to follow the sequence of the lessons as they were taught. The image data was

then analyzed separately to verify and support the descriptive narratives of the classroom settings and the interpretation of the dialogue. Finally, the image data was used to compose iMovies and are included in the Appendices of the dissertation on compact disks (CDs). The movies were used to visually aid three of the teachers in recounting and confirming the events described by the researcher in the observation data. All five teachers were asked to review the researcher's raw field notes for accuracy and provide comments regarding any errors in statements. None of the teachers have contacted the researcher indicating that the accounts documented in the lessons are inaccurate or do not portray actual events and statements.

How data was displayed is important to the interpretation of the results. This study uses visual diagrams, tabulated quantities and percentages, as well as photographic image data.

Teacher Backgrounds, Settings, and Science Teaching

Descriptive narratives about the teachers' classrooms, schools, and science units taught case by case are presented. The purpose of the descriptive narratives is to portray how each of the research participants met the project criteria of an exemplary teacher of elementary science discussed in previous chapters as well as to provide contextual information about their respective settings. The descriptive narratives incorporate teacher perceptions of classroom inquiry and scientific processes, as well as their views about the science curricula they were observed teaching in their respective classrooms. Each portrayal is presented in the order of the three research questions. The assertions are consistent with the third research question and directly aligned with the descriptions in

Figure 2 and the Inquiry Continuum (IC) in Chapter 2. The names of schools and teachers are pseudonyms.

One of the challenges of this study was to look at the processes of teaching: what teachers say and do in their classrooms in relation to established criteria for classroom inquiry. In Chapter 2 of this dissertation, the criteria invoked was the IC as articulated through the five essential features of classroom inquiry presented in *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (National Research Council, 2000). These classroom features were used to form the basis of the assertions resulting from the analysis of the classroom observations conducted at each of the research sites.

Bayside Elementary School: Natalie

Bayside ES was in a suburban school district. The 397 students that attended Bayside School were 97% White, and 3% Asian. There was no ESL or bilingual education at Bayside ES, and 3% of the student population was eligible for free or reduced lunch. About 14% of the students received special education services. Bayside School is situated in an upper-middle-class neighborhood. Trees and well-groomed, single family homes surround the single-story brick building.

There was a marine mural decorating the walls of the school's main entrance, which greets visitors with a colorful interpretation of an ocean environment. Visitors to Bayside Elementary School were required to sign in at the main office. Parents were regular visitors to the building and classrooms throughout the field study.

Natalie has an impressive 26-year career as a teacher. She taught first, second, and third grade students in a multiage classroom at Bayside School. She was a middle-aged, White female, with a very erect carriage and careful enunciation.

Natalie introduced the researcher to the building principal during the pre-observation interview and to the other faculty at the first classroom observation in an impromptu gathering in the faculty room.

Natalie taught science for one to two hours per week. Although Natalie stated that there was sufficient time to teach science, she noted on her survey, "If the school day were longer, there would be more time for integrating science into other parts of the day or curriculum" (Survey response, September 2002).

Natalie indicated support for teaching science at her school was coordinated and a prominent aspect of community involvement:

> We have a PTO science chairperson and committee, who help extend science. One teacher serves as science coordinator (sponsors special science day; coordinates efforts of PTO, [and] orders supplies). Parent volunteers help with science lessons. (Survey response, September 2002)

The principal, parents, other teachers and students, and outside visitors frequented the classroom during the observations conducted at Bayside School.

Natalie has earned a master's degree, completed six undergraduate science courses and one graduate science course. She has been involved in the LSC as a Round One (1994–1995) teacher and KS. This National Board Certified teacher had an excess of 250 hours of LSC professional development, and she has taught all nine of the elementary school science kits for two or more years each as a multiage teacher. She

distinguished her career in elementary school science reform locally by having served on numerous committees, the LSC advisory board, training colleagues, piloting kits, and mentoring new teachers in elementary science teaching.

Natalie's Classroom and Students

Natalie's classroom was wall-to-wall carpeted and full of visually stimulating samples of student art and written work. A banner acknowledging the multiage collaborative hung on the wall in the classroom. Numerous books were stored in bins along the cubby-style bookcases that lined one whole side of the classroom below the windows. Books also filled the spaces of the windowsills. The books were separated according to categories and topics, such as multiculturalism or oceans. Students' desks were grouped so that the 21 students were seated in four groups of four and one group of five. A teacher desk/station with a computer was situated near the classroom entrance. There was a curtained doorway connecting Natalie's classroom to another classroom.

Students were assigned roles during science that facilitate social responsibility and the flow of activity. Natalie's voice tended toward softness in volume and was never raised except in laughter or excitement about ideas from students. She clearly enunciated and used measured pacing when delivering instructions to her multiage classroom of learners. She maintained an active record in her head of who has and has not contributed during whole class sharing and discussion. She acknowledged every contribution made by the children and used repetition of children's responses as an opportunity to reaffirm, confirm, correct, or validate previous responses. Although, Natalie probed for the "what

else" or "what can we say that is different," she accommodated the needs of her youngest learners to provide direction and modeling.

Multiage cooperative groups were balanced with a distribution of Youngers, Middlers, and Olders. The Olders were the students who by age and development would be third graders in a single-grade classroom. The Middlers were the traditional second graders, and the Youngers were the first graders. Olders captain their science teams and were responsible for assigning the role of "getter," reading for Youngers, and helping Youngers to read and write. Olders took their roles seriously, while assuming responsibility for their own learning and performances. There was one child identified by the researcher as a traditional minority. There were two adults in the room, Natalie and her aide, Mary. The aide shared in the responsibility of preparing lessons and assisting learners with materials and questions. Natalie described Mary as respectful and aware of her goals with learners in the classroom. Mary prepared materials and equipment, graded papers, and worked one-on-one with the only identified special needs learner in the class.

The Curriculum Unit: Water (FOSS)

The FOSS water kit is designed as a seven-week, four-activity unit for grades three and four. All of the unit activities were taught and observed during the study. The unit overview (Lawrence Hall of Science, c1993) indicates the themes addressed by the unit are: pattern, structure, interaction, change, and system. "Water's unique properties" describes the science concepts to be investigated. The teacher's manual provides general instructional suggestions and directions for setting up and using the provided kit materials. Generally, 90 to 100% of the planned activities were observed, and the unit lessons were taught with little deviation from the unit design with regard to concepts and

materials. However, some lessons were sequenced differently to accommodate Parents Day.

Figure 9.
Title: Water Unit Instructional Sequence.

Designed Activity Sequence	Implemented Activity Sequence
The Water Works: surface tension, flow	The Water Works: surface tension, flow
Hot Water, Cold Water: expand, contract	Hot Water, Cold Water: expand, contract
Water Vapor: water cycle, evaporation, condensation	Testing the Water: hard, soft, chemical indicators
Testing the Water: hard, soft, chemical indicators	Water Vapor: water cycle, evaporation, condensation

The unit goals expect students to

- Observe and explore properties of water in liquid.
- Observe the expansion and contraction of water as it gains and loses heat.
- Investigate factors that influence the cycle of evaporation and condensation of water.
- Compare water quality using indicators.
- Observe changes that occur in water that has flowed over limestone.
- Record observations in writing and pictures.
- Exercise language, social studies, and math skills in the context of science.
- Become aware of the importance of water in their lives.
- Gain experiences that contribute to their understanding of several pervasive themes that point out connections among scientific ideas and processes: patterns, structure, interaction, change, and system. (*Water Teacher Manual*)

Students kept science journals/notebooks where they recorded their findings and drawings from investigations. Students' journal entries served as formal assessments throughout the unit.

Perceptions of Classroom Inquiry

Natalie's perceptions of science inquiry and inquiry teaching were captured through direct interview and through the analysis of her classroom practice. Natalie expressed a definition of inquiry grounded in hands-on experiences that model what scientists do within a social environment to promote the exchange of ideas.

> To me, inquiry means having children discover through a hands-on approach basic science principles, to get them to explore [with] real tools and be scientists. [They need] guidance from you in approaching a task-[in their] cooperative group [they can] explore, discover, investigate, inquire, and ask each other first, [then] pose to the teacher. The teacher can respond and pull from the kids. [You want to] suggest. You don't want to spoon feed. It doesn't empower. [You want them to] see it is fun and build on their curiosity, [which] influences how they think about science . . . (Pre-observation interview, September 12, 2002)

Natalie placed emphasis on asking science-related questions, conducting science investigations using science tools, and engaging in analysis through discussion. When asked what sort of instructional strategies might be observed in her classroom, Natalie described her approach to inquiry as having multiple phases:

1. Establish the purpose of the lesson or investigation: what we want to find to out.
2. Model necessary and appropriate science processes, such as questioning, recording, and using science equipment: what we are doing.

3. Monitor learners' actions and survey learners' thinking with reflective pauses as the investigations progress; have students report out and share their findings: what we are thinking.
4. Direct and reinforce scientific understanding that results from the events of an investigation: what is the science explanation.

   [I] set up and let them know what to try, what to think about, [what] direction to focus [their] thinking. [I do] model part of the lesson and stop, so they finish. [I] will ring a bell, and there is a lot of predicting and brainstorming questions. What do you think will happen? Try to find out. [When there is the] unexpected, I'll say, "See if you can repeat that." [It] is fun to see other things happen and expand the repertoire in their minds. [I] use the easel [to write] the title and draw a diagram [to discuss] what was learned. So I think they focus a little, but [I don't want to be] too directive, [I want to be] encouraging. When I hear a good science sentence, [I] reinforce very specifically and listen for it right away. (Pre-observation interview, September 12, 2002)

5. The teacher creates the expectation that there will be a necessary "hum" of activity in the learning environment indicative of learner interactions with each other and their explorations.

The field study was conducted during the beginning of the school year. Olders and Middlers were responsible for modeling for the Youngers. As the study progressed, it became evident that Middlers and Youngers were able to assume more responsibility within the team. For example, when an Older captain was absent, the role of getter went to a Younger and the role of captain was taken on by one of the Middlers in the group.

This structure facilitated instruction by having learners be accountable for individual performances as well as group performances. Olders and Middlers were responsible for ensuring that writing and reading were performed to support the Youngers as well as their own learning experiences. Youngers, Middlers, and Olders were called on during lessons to describe, share, and ask questions. This cooperative management of the science lessons was interpreted to reinforce to learners that science is done and valued by everyone in the classroom. Many of the early childhood science skilis requiring basic manipulation of materials were shared among group members, although these tasks were especially important and friendly to the Youngers. The teacher describes the activities:

> [The classroom is a] very busy environment. It hums in here. [It's] not loud, not quiet. [I] give [the] instructions, expectations, [and they] work independently. [The] captain members are first in line. [There are the] roles of "getter" and "recorders," taking turns involving people in the group to reinforce by participation. [They] need to be responsible. . . . but [they also] see [how to] stop and reflect on what has happened so far, where to go next, [and] bring closure [to] what [they] did today. . . . the team is working: leaning, standing, holding, pouring. [There is] active involvement on the kids' part. (Pre-observation interview, September 12, 2002)

Natalie's interpretation of inquiry was described as being present "in everything we do." She viewed inquiry as a process that was not limited to science, but as an inclusive and intellectual process of being "guided" that can be applied across the elementary curriculum and was especially suited to the needs of a multiage classroom.

> In the multiage collaborative, we use it in everything we do. It's evident in reading and math. [The] kids take [to] it naturally. They know we'll guide them. They guide another child. They don't know another way. [It] is how we learn, how we work together to the level of their ability. . . . [It] allows for individuality. There is a huge development continuum and everyone is accepted, participates, nurtured, encouraged. (Pre-observation interview, September 12, 2002)

Despite Natalie's obvious belief and preferences for inquiry as a teaching and learning approach, she also described the limits of what can be done when teachers have to negotiate "what is pulling on you" in schools.

> Writing standards and expectations have increased. [The] criterion on the rubric writing assessment demand so much attention—in math, it is problem solving. (Pre-observation interview, September 12, 2002)

Where possible, Natalie integrated across content areas to make science a more inclusive part of the larger elementary curriculum.

> When we did sound [the kit], we combined sound with music instruments and invited parents [to hear] the science of music. (Pre-observation interview, September 12, 2002)

Natalie believed in the use of kit-based science to bring science into elementary classrooms; the kits make science accessible to teachers and students. The difference between elementary school science and professional science is the amount of time needed to conduct investigations. The kits guide inquiry by Natalie's standard for inquiry. Natalie has always enjoyed teaching science, but focused more on Earth and life sciences prior to the LSC. The kit-based curriculum required her to teach physical science, and it

has been an area of professional growth for her as a result. Natalie did express preferences for certain kits. For example, the FOSS Water kit was favored owing to the degree to which it allowed students to openly explore and observe with their senses. Water is a yearlong theme within the multiage collaborative at Bayside ES, so the FOSS Water kit was the first science of the year taught via the science kits. During the post-observation interviews, the researcher asked Natalie how she felt about the FOSS Water unit and inquiry; did the kit hamper science inquiry:

> [I] love the water kit and how different kids [are] able to really use and get something out of it. Something always happens. . . . Sometimes [we] can do more in one direction. [A class one year], they went off on the water cycle [and] collect[ed] more samples from around the world, [including] the Black Sea. [On a] map [we had] . . . samples [of water] from all over the world [connected] with string, which was something that [our] class did, [but] we didn't do [that] this year. [The kit] allows for flexibility . . . to go with the interest of students. (Post-observation interview, December 20, 2002)

This expression for how much and in what ways the Water unit was valued suggests that Natalie's interpretation of inquiry allowed her and her learners the freedom to move in meaningful directions with the unit goals and concepts. The value of the science content to the children and the teacher was another important characteristic of the unit that served to energize and fuel the teaching and learning in the field setting as much as the teacher's past success with teaching the unit.

> [Children are] always looking for a way to connect to [their] own lives, and I pull from them rather than tell them. . . . [I] like [the Water] kit for many reasons.

[The] meaningfulness of [the] topic; it truly is an important Earth material to be used with respect. [It is] worthwhile to teach them . . . (Post-observation interview, December 20, 2002)

The approaches to teaching and the structure of Natalie's multiage classroom as described by her, conformed to the basic essential features of classroom inquiry (NRC, 2000). Through the kit-based science units, elementary learners were presented with scientifically oriented questions, and although learners' questions were not always pursued (or teacher's questions for that matter), there was flexibility for building upon students' interests and questions. The interview data suggested that learners were asked to report and share the events and findings of their science investigations, which means that they were also communicating about science.

Classroom Observations

The researcher completed nine observations at Bayside ES in Natalie's multiage classroom between September and November 2002. The resulting assertions are based on the analysis of classroom observations and will be presented in association with the five essential features of inquiry as represented along the IC. Coded classroom interactions are used to substantiate the assertions. A brief summary of the findings is also presented at the end of the portrayal depicting the degree to which Natalie is considered to engage learners of elementary science in inquiry.

HOT

Figure 10 presents the total time spent by the researcher observing the multiage classroom. An estimate of the total time observed that was spent using the kit materials

and engaging the learners in hands-on activities was determined from the observation data.

Table 10.
Title: Use of Classroom Time .

Total Minutes Observed	% HOT	Average # of Min. Observed/Class
599	32	75

The average amount of time spent by learners engaged in hands-on activities was found to be approximately one-third of the science instructional time. Students during this time were engaged in those processes consistent with early childhood guidelines relevant to science learning (Chaille & Britain, 2003). The learners controlled the events and changes in the systems investigated, which were reasonably immediate, with the exception of the evaporation activity. The unit activities involved students in science processes of observing, predicting, and manipulating tools in support of either asking or answering a "scientifically oriented question." The questions asked were directed by the curriculum and presented for interpretation by Natalie. During whole class instructional time, the curriculum questions directed the investigations that the learners performed. However, within the teams, students were given opportunities to answer and explore individual or group questions that developed as a result of hands-on experiences. Teacher statements and questions were structured to motivate learners and their activities to lead them toward more divergent thinking.

> Teacher: [I have a] challenge [for] you. What happens to beads [of water] as more and more water gets added? [Students are listening but are also still using the

eyedroppers.] What happens? How close can you drop [water]? What shapes [do you make]? (MOTIVATE, DIVERGENT) (Observation, September 26, 2002)

These types of vocal interventions actively facilitated learners to consider scientific questions while they were engaged with materials.

Natalie also used transitional statements to prepare learners for impending questions and activities related to their investigations.

[Teacher moves around the room and spends time at each table with learners. Teacher rings the bell (hand bell with clapper) indicating time to stop. Teacher reminds students not to let eyedropper touch water on the penny.]

Teacher: Be ready to discuss shape. (INSTRUCT) (Observation, September 26, 2002)

Again, these vocal interventions during hands-on learning moved the children to think about their hands-on experiences in relation to an intellectual pursuit to establish a connection between physical events and science knowledge. The nonhands-on time was spent doing several things toward this end:

1. Reviewing the events of their hands-on activities—learners describe what they did.
2. Looking at the results of the natural events—what happened.
3. Interpreting or trying to make sense out of what happened—explain using the evidence.
4. Communicating these things effectively, including writing or representing the events in a notebook/journal dedicated to science investigations.

NHOT

Natalie's actions and statement were highly integrated and driven by the need to teach the intended curriculum while being responsive to the learners in class. Natalie structured the nonhands-on time (NHOT) during science lessons throughout the unit to:

1. Organize learners and materials.
2. Present the topic of investigation.
3. Discuss with learners what they already know or want to know.
4. Define and describe scientific terms and events.
5. Document or model documenting scientific information.
6. Conduct instructional demonstrations of investigative set-ups and materials to be used.
7. Analyze the results of investigations with learners.

Class time was structured using a blend of instructional approaches or styles that included direct instruction (didactic), lecture-discussion (monitoring and surveying), as well as cooperative grouping (child-centered interactions). The unique blending and sequential transitions between approaches created opportunities for learners to connect their HOT experiences with scientific language and ideas. For example, Natalie accommodated the diverse needs of the learners in her room by using demonstration and lecture-discussion approaches to introduce the language and concepts of more and less dense.

[Teacher goes to get the objects to be used in the investigation. Students stay quiet and seated on the rug as the teacher returns with a tray of materials.]

Teacher: [This is a] cup of what kind of water? (CONVERGENT)

Student 1: Room temperature. (Recall)

Teacher: [I have these] objects. [Lets] see what happens when I drop it in. (INSTRUCT, MOTIVATE to predict, ATTENTION GETTING)

Student 2: It will float. (Prediction)

Teacher: Does everything float? (CONVERGENT)

Student 3: No. Rocks don't float. (PRIOR KNOWLEDGE)

Teacher: This floats, because the cork is less dense than water. [Teacher places cork object in water.] When something is less dense than the water it floats. [Teacher asks for the prediction on next object.] How many think it will sink? (DEFINE, DEMO, CONVERGENT) (Observation, October 17, 2002)

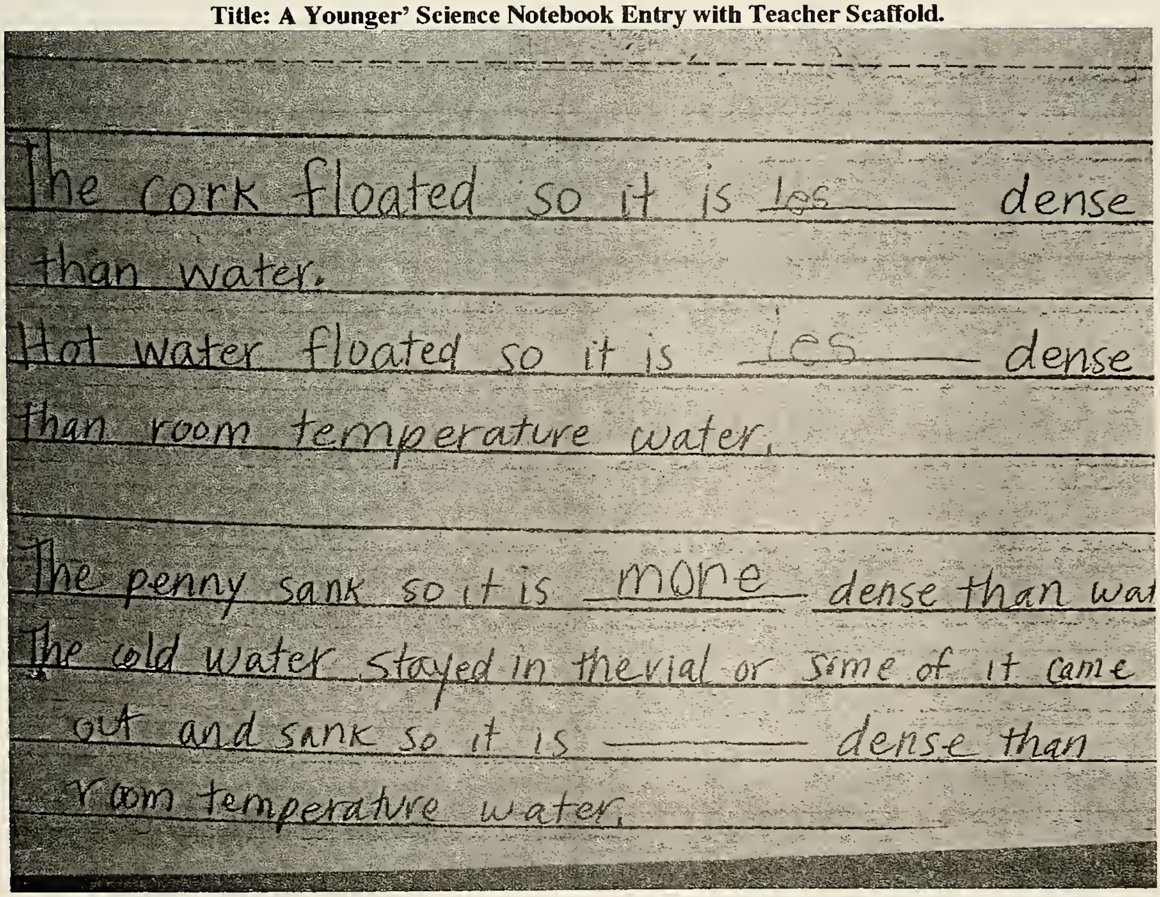
Some of Natalie's statements were clarifications, acknowledgements, and recognition of learner statements, which were emphasized or restated owing to their significance in formulating important science knowledge. There was also vocal emphasis added to key remarks and statements. In the above example dialogue, Natalie intentionally connects the students' existing language and conception of "float" to "less dense" and uses learners' responses to develop scientific definitions and explanations. This awareness in her teaching merged learner's existing knowledge that some things float in water with the "scientific naming" of the phenomenon, less dense. Natalie's approach to how and when to "scientifically name" conceptions and events (e.g., label the evidence or the explanation) stems from her prior experiences teaching the unit and her knowledge of the learners in her classroom. In the past, she has learned that density is a challenging concept for all of the learners to grasp without specific, focused scaffolding by the teacher. There are some learners, such as the Youngers, who require more explicit and

direct instruction, while the Middlers and Olders are more likely to grasp the concept of density with teacher guidance.

Variations in sense making by learners through their combined experiences with the teacher demonstration, hands-on investigation with cold and warm water, and small group discussion were captured in students' journal entries.

A Younger's entry (Figure 11) is scaffold directly, because the teacher has provided fill-in-the-blank prompts. This instructional and assessment action by Natalie relied upon the pre-investigation demonstration and discussion to help support the learner's interpretation of the investigative observations.

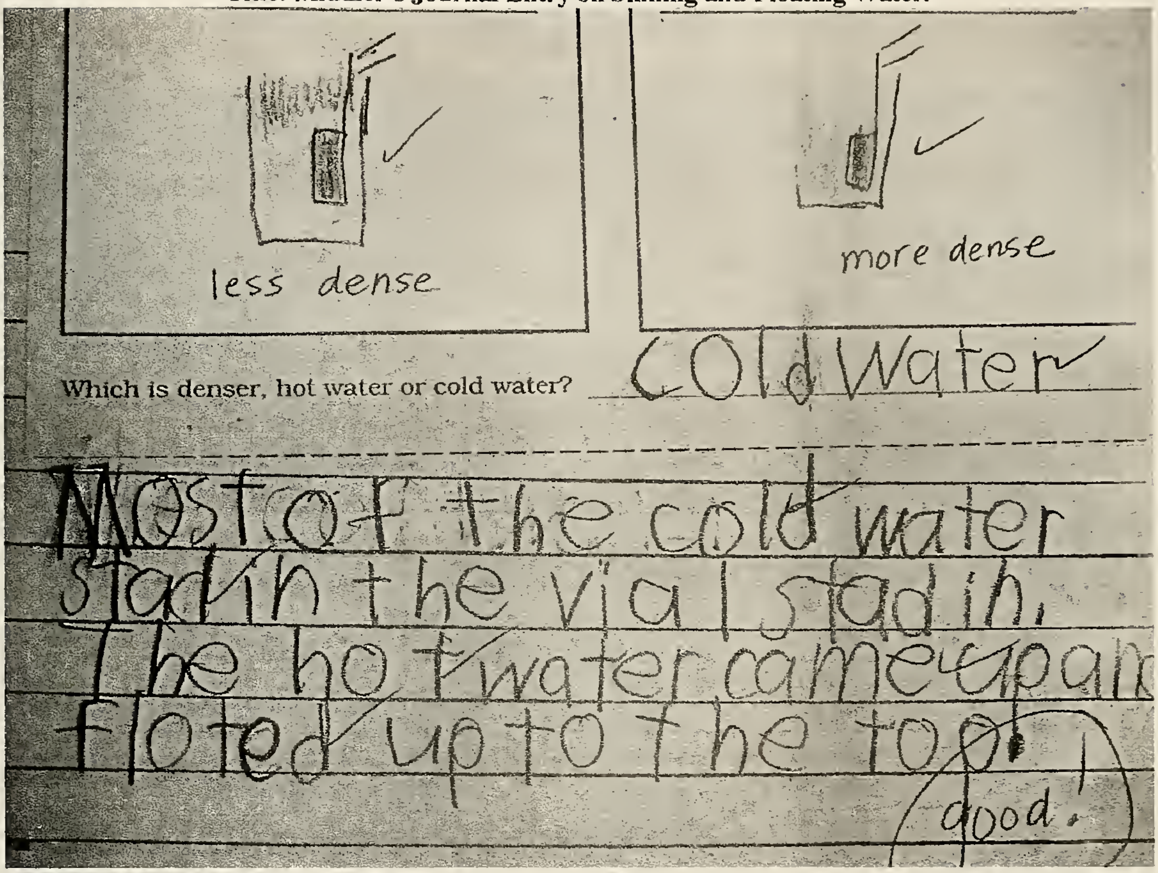
Figure 11.
Title: A Younger' Science Notebook Entry with Teacher Scaffold.



The fill-in-the-blank teacher prompt acknowledges the students' language ("float" and "sank") from the lecture-discussion. Natalie then prompted the association of this language with "less dense" and "more dense." The intent was for learners to begin to substitute science names for the names they already gave the phenomenon. The teacher simultaneously modeled the use of written language to communicate science ideas for this emergent-level reader.

The Middler's entry in Figure12 illustrates the documentation of investigative evidence by the learner, but the teacher reinforced the new science name for the evidence described by the learner under the student's drawing. Again, this was a teacher action that affirmed the student's thinking about the evidence, but invites the use of science names and words.

Figure 12.
Title: Middler's Journal Entry on Sinking and Floating Water.

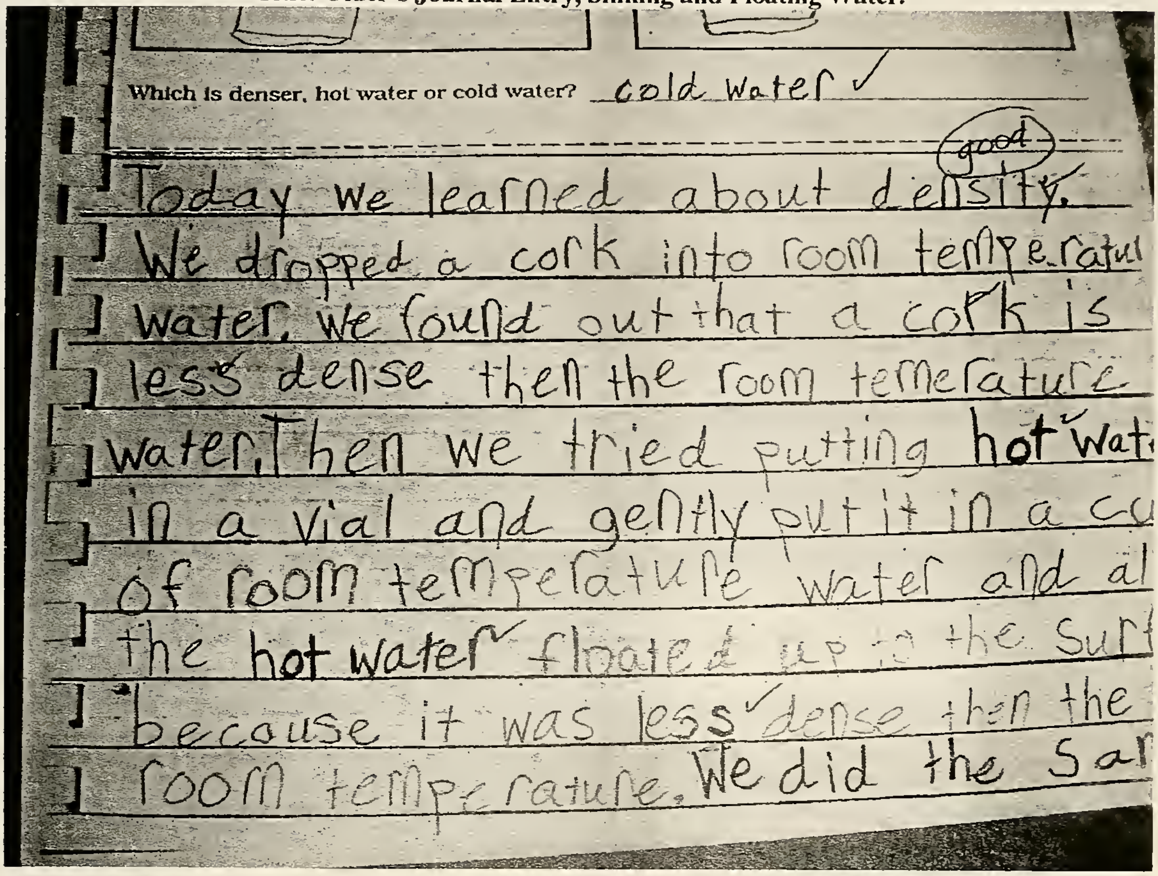


This entry also illustrates the communicative differences between Youngers and Middlers. Like her younger classmates, the Middler learner recognized and accurately recounted the events of the investigation, but she associated the observed property of density using child-science language. Rather than using less and more dense or invoking the word "sank," the learner's entry remains more descriptive (evidence-based) rather than explanatory. This is significantly different than what was recorded by most of the Olders in class.

In the Older's entry in Figure 13, it is apparent that the learner has connected the full sequence of instructional events to scientific evidence and explanation. The learner

integrates much more scientific language, and he was able to clearly identify what the topical concept (e.g., objective) was for the lesson.

Figure 13.
Title: Older's Journal Entry, Sinking and Floating Water.



Which is denser, hot water or cold water? cold Water

good

Today we learned about density.
We dropped a cork into room temperatu
water. We found out that a cork is
less dense then the room temerature
water. Then we tried putting hot wat
in a vial and gently put it in a cu
of room temperature water and al
the hot water floated up to the Surf
because it was less dense then the
room temperature. We did the Sa

Natalie's observations of learners during their hands-on time allowed her to identify moments when it was appropriate to stop the hands-on investigation and reflect on the observed events with learners as a whole class. The teacher integrated specific attention-getting actions and statements with purposeful divergent and convergent questioning.

Scientifically Oriented Questions

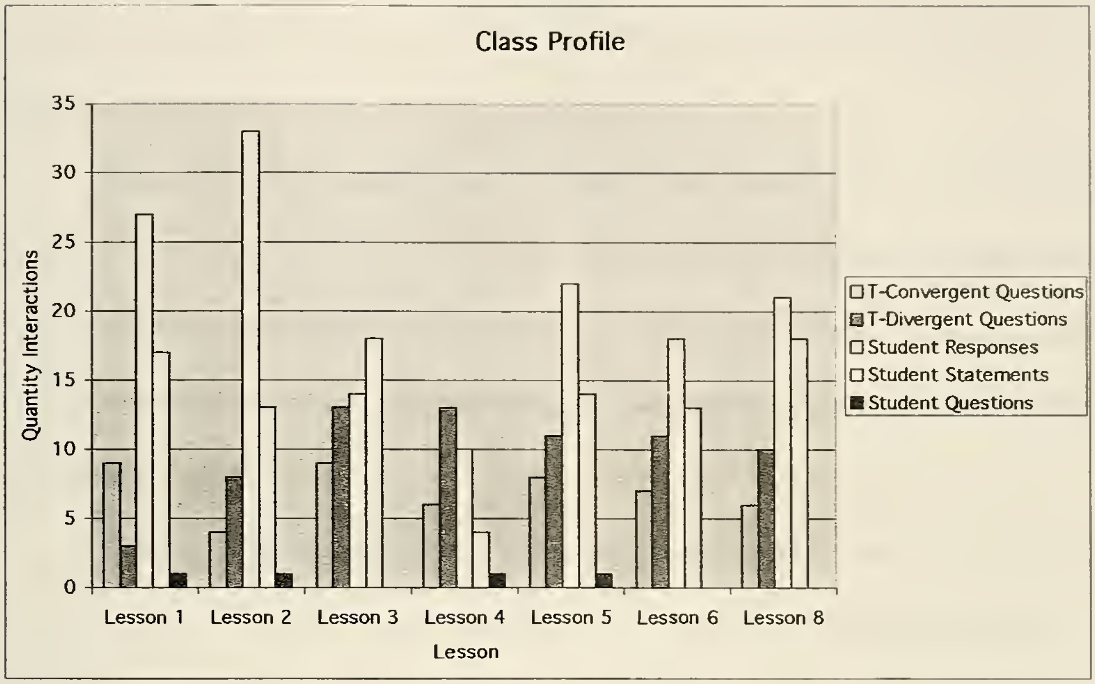
Assertion N1 (AN1): Learners were engaged in scientifically oriented questions. During hands-on time (HOT), the unit question(s) presented learners with a query such as, "How many drops of water will fit on a penny?" Preliminary and follow-up questions

were asked during NHOT segments of lessons. The classroom teacher and the curriculum materials provided the questions investigated.

Natalie's lesson structures were consistent. She began by either preassessing learners' thinking, reviewing prior investigations or science lessons, or announcing what students were to study. This was done using a demonstrate/model, lecture/discussion approach to transition the learners to science, while everyone was seated on the carpet area. These periods of set induction, using lecture/discussion, ranged from about 15 to 20 minutes. Natalie then modeled or demonstrated what it was that learners needed to get for materials and how to use them during the investigation. Specific details about what to do and how to configure the system of materials were presented to the learners, as well as, what data to collect. Once learners were in their groups, they were left to their own devices to set up and collect data. Stop points also marked Natalie's instructional profile when a bell was used as an auditory cue for learners to stop and give the teacher their attention. These stop moments were arranged to provide learners a chance to report their findings and observations, to share/ask questions, or for the teacher to transition the learners to the next part of the investigation or task.

As a part of the analysis of the classroom observation data, the numbers of convergent and divergent questions were identified in each lesson, except for Lessons 7 and 9. Lesson 7 was an abbreviated lesson due to parent visitors in the classroom, and Lesson 9 was a teacher-created extension lesson to the kit. The teacher's questions were plotted to determine if a pattern was evident in the distribution of the two types of questions.

Figure 14.
Title: Natalie's Whole Class Profile.



The number of divergent questions increased after Lesson 1 and remained the predominant type of question posed over the course of the unit. During the unit, Natalie was asked what guided her questioning of learners. She responded that her "content knowledge and knowledge of the child" (Interview, October 31, 2002) guided her judgment about what questions to ask and who to call on in relation to an asked question.

> A bit of it is that you really need to know the students in order to pull out the information through measured probing. [Part of] it is the reading and writing ability, and if the social [interaction/development] is okay. If not, I may not go there. . . . Teachers are making so many decisions when calling on students. (Interview, October 31, 2002)

The data supports the complexity alluded to by Natalie when engaging in questioning as an instructional strategy. There are scenarios in the data that illustrate Natalie's decision making during the responsive moments of instruction.

Divergent questions can be used to initiate and facilitate discussions that allow the teacher to funnel her questions toward more convergent ones. The instructional outcome is for learners to refine their initial responses to the divergent question. In such instances, it is the combination of divergent and convergent questions that shape the development of content knowledge.

> Teacher: Look up here, please. I need your help. [Students take seats]. What did it look like? (MANAGE/DIVERGENT) [Teacher draws on easel.] (MODEL/ DOCUMENT)]
>
> Student: When you dropped it, it just rised like a flower.
>
> Teacher: [It] spread out. So, when I dropped [the water] on paper towel [it] absorbed. It spread out. [Teacher draws a picture based on restated student observation or descriptions.] (CLARIFY/MODEL/FACILTIATE/ EMPHASIZE)] (Observation, September 19, 2002)

Divergent questions were also posed to facilitate learner focus and guide learner actions during an investigation without explicit directions from the teacher. It was possible to couple these divergent questions with motivational statements to invite exploration.

> Teacher: What would you guess? A big drop or a little drop will go faster? Try it and see. Can a drop chase another one and catch it? (DIVERGENT/MOTIVATE)
>
> Student (choral): Yes!

Teacher: I don't know, you'll have to try and see. (MOTIVATE/DIRECTION)

(Observation, September 19, 2002)

Natalie relied upon convergent questions to assess the acquisition of vocabulary and basic science knowledge directly. As the data indicates, these questions were minimal overall. Convergent questions can reinforce vocabulary and important science knowledge.

Teacher: [Teacher writes on the easel.] We dropped a drop of water onto four different papers. The wax paper made a bead. The paper towel—(DOCUMENT) What? [Prompts students to complete the sentence using target vocabulary.] (CONVERGENT)

Students [Choral response]: Absorbed. (Observation, September 19, 2002)

Natalie also used a convergent-to-divergent sequencing of questions. A convergent question was asked to assess for such things as proper vocabulary use and concept attainment before moving on to more divergent thinking about the content. For example, after investigating evaporation and condensation, Natalie asked students to describe or define what condensation was before they began a lesson on the water cycle. The multiage composition of the class allowed the Olders to anticipate the direction of the lesson, while the Youngers and some of the Middlers had time to consider and reflect upon what will come next.

Teacher: Where can we get new water? (CONVERGENT FOR OLDERS/ DIVERGENT FOR YOUNGERS)

Student 1: Nowhere.

Student 2: Jupiter.

> Teacher: It is so important we're respectful of planet Earth. Evaporation, condensation, and one word I haven't said yet. (SUGGEST)
>
> [An Older reads "precipitation" from the water cycle chart held by the teacher and offers examples of hail and snow. Some students note that rain puddles evaporate.] (Observation, November 14, 2002)

The presentation invited or motivated learners to share their thinking. In effect, by the teacher's acceptance of their remarks, the students sustained the dialogue and informed each other.

Although the field study intent was to focus on the teaching process, it is noteworthy that the students' questions were infrequent in the data as illustrated in Figure 14. Students principally responded to the teacher's questions and statements or asked clarifying questions. This is thought to be so for two reasons: (1) the researcher was unable to record student-centered questions effectively, due to the practical limitations of what could be recorded, and (2) students did not ask many of their own questions during whole class discussion. There are few instances in the data where the teacher has asked learners to formulate their own questions. This does not mean there were no instances when students did not generate their own investigation questions or pursue them. There was sample data to support individual learners posing questions.

> Teacher: [Student] had a wonderful idea. [He wants to] try [the investigation] at home using a quarter. Do you think more or less [drops of water will fit on the quarter]? Can you try different coins? It would be interesting to see. (Observation, September 26, 2002)

In the same lesson, another student promoted her own investigative moments during the planned lesson by posing this question to the teacher:

> Student: What if you accidentally put two drops [of water]? (Observation, September 26, 2002)

The learner reconceptualized and extended the assigned investigation. The teacher encouraged the learner to follow directions, but also suggested that "errors" should be examined as part of the investigative process.

Priority Given to Evidence

Assertion Two (AN2): Learners were directed to collect certain data. Natalie always modeled or documented the essential data from her investigations with learners. The image data as well as the observation data document the extent to which Natalie provided direction during data collection. The data was used to facilitate and focus whole class discussions about the nature of the phenomena being investigated.

Natalie adhered to the guidelines in the teacher manual with regard to evidence. Students recorded their findings in their science journals. The teacher simultaneously conducted whole class discussions of the results, while writing on the easel. The easel was prepared in advance to replicate the journal entry pages provided in the teacher's manual.

During the first lesson, Natalie described for all of the learners the value of a science journal.

> We'll be doing more experiments in the next three weeks. [Write] what happened, so you can go back and look in your science journal. (Observation, September 19, 2002)

A question regularly asked by Natalie was, "What do you notice?" Students were directed to address the experimental results in order to begin an analysis of the evidence. This was the first step toward formulating evidence-based explanations.

Formulating Explanations from Evidence

Assertion Three (AN3): Learners are guided in the process of formulating explanations from evidence. Students were asked to describe their observations as a basis from which to begin making sense of the investigations. The teacher emphasized, recognized, and acknowledged learners' statements that moved the whole class discussion toward the desired conceptual goals. In lesson five, Natalie moved learners to use their observations to offer an explanation for what they saw when they placed a vial of red, warm water and a vial of blue, cool water into a container of room temperature water.

Teacher: What did you notice about the blue [colored water]? (DIVERGENT)

Student 1: It went down to the bottom. [His] looks really good.

Student 2: It's more dense, so it won't go out [of the vial].

Teacher: This blue water is still in the vial so it's stuck down there. It won't come out. If your cold water starts to warm up, what will happen to it? (RESTATE, DIVERGENT)

Student 3: It will come out.

Teacher: [Student 4] made a good observation [that] all of the water in the red vial is out and all of the blue water is not. (ACKNOWLEDGE)

Students: Hot water is less dense [choral response] and the blue water is more dense. (Observation, October 17, 2002)

The students utilized their observations to formulate an explanation for the behavior of the two waters with the guidance of the teacher.

In one instance, learners struggled to offer a reasonable explanation based on their empirical observations. The incident was consistent with the theory that learners maintain an alternative conception in the face of a contrary experience. In Lesson 6, Natalie presented learners with the problem of a balance that had ice on one side and water on the other. The respective cups' contents were at the same height in the two identical cups. Students predicted the ice would be heavier than the water. When the water proved to be heavier than the ice, they had difficulty reconciling the observation with their existing notions of density. During the discussion, one student articulated, "It's frozen and ice weighs more . . . no, water weighs more than ice" (Observation, October 24, 2002). Despite direct observation, learners were not necessarily ready to move toward an alternative explanation of their sensate experiences without the teacher's support.

Connecting Explanation to Scientific Knowledge

Assertion Four (AN4): Learners are directed toward areas and sources of scientific knowledge. Natalie facilitated learners' explanations to scientific knowledge. This happened in three ways: (1) students made connections across lesson experiences, (2) the teacher brought additional information to learners, and (3) learners were encouraged to seek out additional sources.

This was particularly evident in Lesson Eight. Students had conducted the evaporation investigation and were asked to observe the process of condensation. Through a process of descriptive statements and questioning, learners were guided to connect their explanations to prior experiences.

Teacher: There was water on the outside of these cups. (FACTUAL DESCRIPTION)

Student 1: When we added ice, the fog started building up more and more. [Teacher writes.] (DOCUMENTS/MODELS)

Teacher: What do you think was happening to the cup? (DIVERGENT)

Student 2: Getting colder.

Teacher: [The] colder it got, the more fog. Where do you think the water came from? [Meaning the fog on the outside of the cup.] (EMPHASIZE, ACCEPT, RESTATE, DIVERGENT)

Student 3: The air.

Teacher: When we evaporated water, it went into the air and is still there. When you change water vapor in the air back to water, you have to cool it. So, how did I, we, cool it? (ACCEPT/RESTATE/FACTUAL/CONVERGENT)

Student 4: With ice.

[. . .]

Teacher: Think about when you take a hot shower. Do you notice anything in the bathroom [that] gets steamy, foggy? (DIRECT/CONVERGENT)

Student 5: When I get out of the shower [it's] foggy, the doorknob and mirrors.

Teacher: What about in the middle of winter [when you] go outside? (DIVERGENT)

Student 6: You can see.

Teacher: When you breathe, it has water vapor. [It] gets warm, [and] when you breathe it out on summer day [it] doesn't turn into water. But in the winter [it] hits

the cold air and turns back into teeny drops of water. (FACTUAL) (Observation, November 14, 2002)

Discussion that blended convergent and divergent questions with factual and descriptive statements modeled the thinking processes used to connect daily experiences with scientific investigations and knowledge. It also ensured that Natalie effectively modeled question development and alternative ways to think about science knowledge in relation to learners' daily lives.

Communicates and Justifies Explanations

Assertion Five (AN5): Learners are coached in the development of communication. Students in Natalie's multiage classroom communicated to each other; to Natalie; to other adults, including parents and the researcher; and by writing in their science journals. The methods for communication observed during the field study included the use of drawings, diagrams, written text, and verbal exchange.

Students' communications were supported and encouraged by the teacher's statements, actions, and questions. Consistent with good pedagogy, Natalie infused lecture/discussion, problem-based strategies, direct instruction, and cooperative grouping to facilitate the exchange of ideas and information during science lessons. Evidence of teacher statements and questions has already been presented in this section of the case study. In addition to talking in groups and in whole class discussions, Natalie directed students to have another student read their notebook entry to see if it made sense and to make corrections. The researcher observed students reading their journals when they were passed out to students. Students also wanted to extend their capacity to document

and accurately communicate in their journals. One student asked to tape a sample of crystal residue from the evaporation investigation into her journal to archive a sample.

Journals also served to facilitate communication between teacher and students. Natalie employed a system of presenting corrective information or scaffolding entries in learners' science journals. Sticky notes and hand-written comments provided feedback for students' journal entries (See Figures 11, 12, and 13).

Case Summary

Natalie's approach to inquiry was essentially consistent with her pre-observation interview definition. Via the kit-based curriculum, students were engaged in conducting meaningful scientific investigations using scientific tools and processes. The heterogeneous cooperative groups established by Natalie allowed learners to assume responsibility for each other and their own learning experiences. Natalie modeled appropriate methods of data collection, recording, and use of evidence. Natalie structured the classroom discourse with the "judicious use" of questioning and dissemination of factual information. The equitable participation of all learners reinforced the culture that science was an inclusive endeavor built on questions and the pursuit of answers to those questions.

The data in the case story indicated that the essential features of inquiry were present to varying degrees along the IC in Natalie's implementation of elementary school science inquiry.

Pleasant View Elementary School: Rachel

Rachel has been teaching elementary school children for 10 years. Pleasant View School, where Rachel teaches fourth grade had a total student population of 234 in kindergarten through the fourth grade. Ninety-nine percent of the students who attended the suburban school were White. Eleven percent of the students were receiving special education services, and 15% were eligible for free or reduced school lunch. The small school was situated on a local commercial route with nearby strip malls and farmland.

Rachel holds a master's degree and has completed two undergraduate science courses. Rachel typically taught science for four hours weekly. Rachel felt that though there was sufficient support at her school to teach science, she did not have enough time to teach science. Rachel began participating in the LSC seven years ago. As a Kit Specialist, she accumulated over 250 hours of professional development. She has taught four kits since she became involved with the LSC, and she has taught two science-kit curricula for six years, one for four years, and another for two years. The year of the study was her seventh year teaching the STC Electric Circuits kit.

Rachel began each lesson by referencing her lesson plans and reflecting on what she wanted to do. She didn't reflect as much as she should have by her account (Post-observation interview, December 3, 2002). Her 25 fourth-grade students observed and watched her during these reflective moments, where she modeled what thinking looks like. Often there were teaching moments when Rachel paused to ask a question about a circuit or to consider how she might make adjustments to grouping learners given the materials at hand or to consider a question or comment raised by a student. These moments of quiet reflection were often followed by a burst of energy that took her and

the students into the next "big science question" to be investigated, but only if someone (other than Rachel) could form the question first. Rachel focused learners on thinking at the start of their day. Prior to each observation, students were dispersed throughout the crowded classroom at desks, tables, on the carpet area, at computer terminals writing, reading, and engaged in a software game about electricity. On the walls of the small classroom there were teacher-selected posters, and suspended from the ceiling was a science word string (as opposed to a science word wall). The kit box was stored under a table toward the rear of the room, next to the coat closet. The four computers in her classroom were situated at the rear of the room behind the carpeted whole class gathering space. Windows covered the length of the exterior wall. The teacher's desk was at the rear of the room next to the windows opposite the computer stations. The round table in front of the teacher's desk was a place where the teacher put additional materials during science lessons. An overhead was used in front of the only truly accessible blackboard space in the room. Situated behind the board were the coatroom and the door to the classroom adjacent to Rachel's classroom. The most intriguing part of the classroom was a built-in cabinet. The cabinet formed part of the front wall in the classroom near the main entrance to the classroom. A tape deck radio combination boom box was in the cabinet. Classical music could be heard emanating from the cabinet during moments of quiet listening and work.

Rachel and the students began the morning routine by getting their brains going. First, a student led the pledge to the flag. Then the brain exercises began. This physical activity required students (and observers) to cross the body's center by touching alternating knees with hands followed by a visual exercise. The visual exercise consisted

of making eights with the thumb while the arm was fully extended forward at eye level. This was repeated using the opposite arm and thumb. Each thumb created an eight in space first moving to the right and then the left. Once the children's brains were presumably going, the class was prepared to begin doing science.

A culture of equity pervaded Rachel's instruction and interaction with learners. Students in her class requiring special resources were removed from the room. Rachel would not allow the students to leave her classroom without first being grounded in the day's science lesson and establishing a plan for how the learners would re-enter the lesson's activities. As students explored, designed, and trouble shot, Rachel was as much a member of the learning process as any of the students. Interesting questions were written down and/or pursued. If a problem was identified, it was resolved as a community. Rachel's voice was firm, but friendly, and she exuded enthusiasm for learning and teaching science.

The Curriculum Unit: Electric Circuits (STC)

The science curriculum taught by Rachel during the study was Electric Circuits, an STC kit. The 16-lesson unit is structured for collaborative group work. The researcher observed approximately 69% of the designed 16 lessons. Rachel combined lessons as she thought appropriate to complete the unit within the necessary time frame. The kit was scheduled to be returned to the MRC at the end of November.

The unit is divided into three parts and the overview describes the concepts, skills, and attitudes the investigations have been designed to address. Electric Circuits is divided into three parts. In the first part, Lessons 1 through 6, the students are introduced to the basic properties of electricity and learn about electric circuits and the parts of a

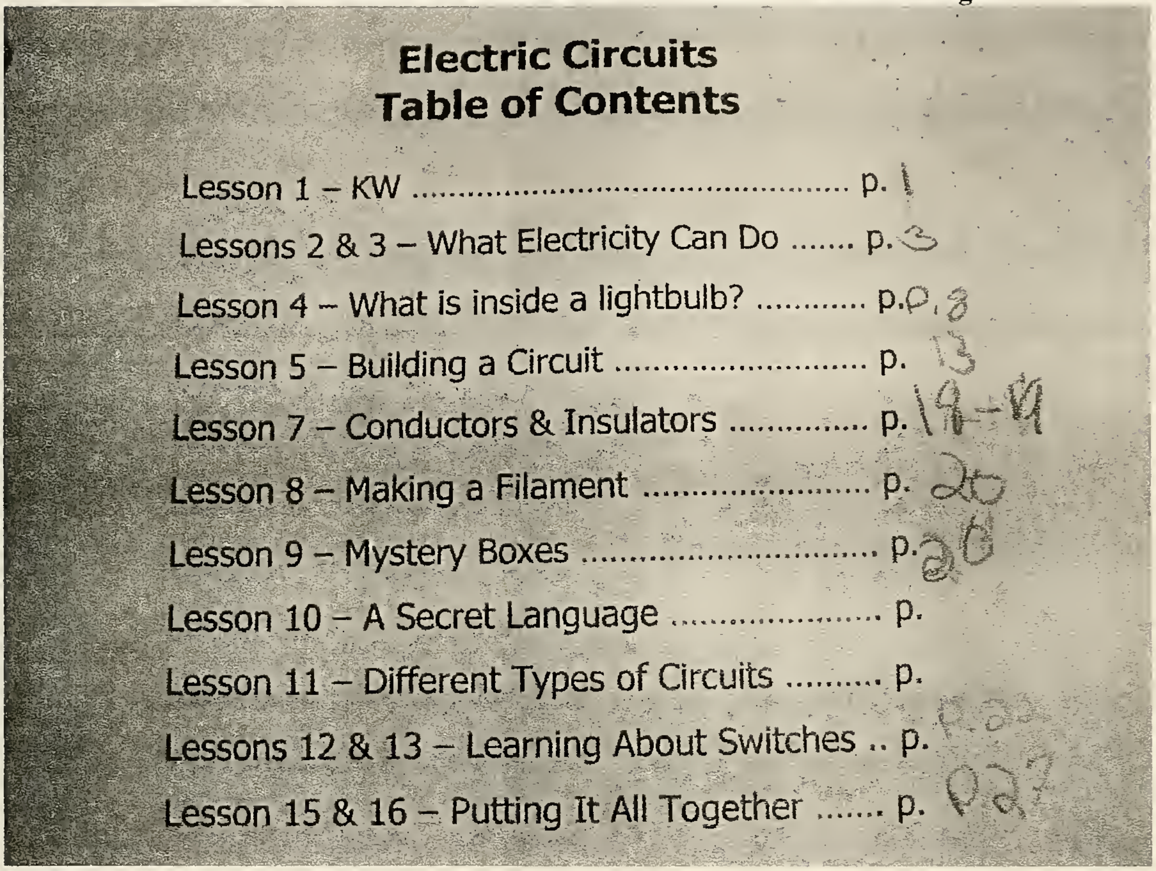
light bulb. During the middle sections, Lesson 7 through 10, students learn about conductors and insulators. They also learn about the symbols used to represent the parts of a circuit in circuit diagrams. In the last half of the unit, Lessons 11 through 16, students explore different kinds of circuits, learn about switches, construct a flashlight, and discover the properties of diodes. The unit culminates with students wiring a cardboard house

Figure 15.
Title: How Unit Lessons Were Combined and Sequenced.

Lesson Numbers	**Lesson Title(s)**
2 3	What Electricity Can Do A Closer Look at Circuits
4	What is Inside a Light Bulb?
5	Building a Circuit
Teacher-Designed Lesson	Review and Exploration
9	Hidden Circuits
10 11	Deciphering a Secret Language Exploring Series and Parallel Circuits
12 13	Learning About Switches Constructing a Flashlight
15 16	Planning to Wire a House Wiring and Lighting the House

As revealed by Figure 16, not all of the intended curriculum lessons were observed. Rachel modified the kit lessons by eliminating Lessons 6 and 14 and by combining certain lessons into a single session. This is evidenced in the following student's journal depicting the Table of Contents.

Figure 16.
Title: Table of Contents from Student Science Notebook o f Lessons Taught.



Electric Circuits
Table of Contents

Lesson 1 – KW .... p. 1
Lessons 2 & 3 – What Electricity Can Do .... p. 3
Lesson 4 – What is inside a lightbulb? .... p. p. 8
Lesson 5 – Building a Circuit .... p. 13
Lesson 7 – Conductors & Insulators .... p. 19-19
Lesson 8 – Making a Filament .... p. 20
Lesson 9 – Mystery Boxes .... p. 26
Lesson 10 – A Secret Language .... p.
Lesson 11 – Different Types of Circuits .... p.
Lessons 12 & 13 – Learning About Switches .. p. p. 22
Lesson 15 & 16 – Putting It All Together .... p. p27

Rachel's instructional time periods on average were significantly longer than any other teacher's observed (106 minutes). This extended time period allowed lessons to be combined. Lessons that were not observed were taught on days when the researcher was not available to observe.

Perceptions of Classroom Inquiry

Rachel described her definition of inquiry as a process of

> Open-ended exploration, asking questions, and determining how you're going to answer those questions. To me, you start off with questions, and in the process of answering questions, you ask more questions. It is very open-ended and scary sometimes as a teacher. (Pre-observation interview, July 10, 2002)

The focus on questions and questioning was what Rachel described as being evident in her classroom instruction during science. It is an area of her pedagogy she said she was "not good" at doing. She described asking questions as the "thing to hone in and improve upon."

> I think, in terms of inquiry, if I ask better questions, I can help create children's questions and get to where I need to go instead [of teaching] by direct instruction. (Pre-observation interview, July 10, 2002).

When asked what I might expect to see in her classroom during science, Rachel elaborated upon this concern and the nature of children in the context of educational experiences.

> You would see me in my classroom providing [children with] materials . . . I hope [that] by providing materials, asking questions about the materials, and [asking] what they [the materials] do, and [the children working] together . . . I am not good [at] asking questions [all of the time]. [For example], I have had technical children who take the materials and work with them. If you have children who like being directed and structured, they get nervous, looking for the right answer. [It is the] nature of education. (Pre-observation interview, July 10, 2002)

This suggested that learners' expectations and the nature of the learner, as perceived by Rachel, impacted her actions during science instruction. Consistent with her initial remarks about the nature of inquiry, Rachel said that the researcher would observe children in her classroom during science instruction

> being constructive, talking, trying new things, grabbing [materials], having heated discussion, looking at what others are doing, looking for guidance, and generally,

they get excited. There will be engagement with materials and each other. (Pre-observation interview, July 10, 2002)

Rachel stated that "inquiry is the true nature of science in terms of what scientists do and what science is," but that the kit doesn't necessarily ensure or "lend itself" to inquiry (Pre-observation interview, July 10, 2002). "Electric Circuits does to a certain extent and some kits do not. I do true inquiry less frequently than I should" (Pre-observation interview, July 10, 2002).

Rachel's early introduction to elementary school science was a textbook curriculum, and she found herself looking for materials to design science activities. When the LSC began recruiting teachers, Rachel piloted kits, found she could follow them, and found that the kits kept the learners engaged in doing science.

Classroom Observations

Eight observations of science lessons were completed in Rachel's classroom. The pre-observation interview suggested that the researcher would see the kit used, as well as children engaged with the materials; addressing scientific-oriented questions either posed by the teacher; the curriculum; or the learners; and being involved in communicating their ideas. Also indicated in the pre-observation interview was the expectation that Rachel would ask questions as a critical part of her inquiry pedagogy. Interestingly enough, Rachel asked numerous questions during her lessons with learners.

HOT

The average number of observed minutes that Rachel spent teaching science was higher than any other teacher in the study. This was the only classroom in the study that did not

have a teacher aide or other adult present during science instruction. As can be seen from Figure 17, learners in Rachel's classroom spent a considerable amount of class time handling materials in relation to answering or asking science-related questions.

Figure 17.
Title: Use of Classroom Time .

Total Minutes Observed	% HOT	Average Number of Minutes Observed/Class
845	37	106

Rachel's overall inquiry-oriented approach relied on a mix of strategies that included lecture, lecture/discussion, and forms of concept attainment (for instance, the use of examples and non-examples of a concept) consistent with the essential features of inquiry. Learners selected their "big science question" to investigate either from a set of proposed questions or via the curriculum materials. In either case, HOT was used to work with materials to answer scientific questions. In some observed lessons, HOT was more structured by the teacher than in others. The majority of the lessons followed the unit guidelines with regard to how they were set up and executed. Rachel ensured that learners had time during the unit and within lessons to work in a manner they chose or to try their ideas. One lesson, in particular, was not a prescribed unit lesson. The lesson was relatively open-ended to allow learners more time with materials and the ideas already introduced about electric circuits. Rachel referred to the lesson as a "mish-mash" of review. The students posed a question they wanted to investigate, developed a plan to investigate the question, conducted the investigation, and presented their findings to the

class. All of these activities are elements of the inquiry cycle or learning cycle as indicated in the STC curriculum.

NHOT

During nonhands-on activities in Rachel's class, discussion was focused on making sense of activity-related events, writing in journals, and communicating about science. Rachel emphasized the importance of planning in her science teaching. It was apparent that the culture of science was as much a focus of instruction as the target content of the kit.

> [Students get boxes and begin to work. They do not plan first.]
>
> Teacher: I see people working but there is no planning. How are you going to record? I don't see any evidence of that. I have to see you plan and how you're going to record. If you're done [doing that] put your hands on your head. It has to be neat.
>
> [Students begin the buzz of discussion and planning as the teacher walks around encouraging, reminding, prodding, etc.]
>
> Teacher: If I see no writing or plan, I'm going to shut you down. (Observation, October 22, 2002)

As this lesson on October 22, 2002, proceeded, it became apparent that learners did not really know how to set up a recording system for the task at hand, which was to test for complete circuits in 14 boxes with a circuit tester that they had to first build. Rachel realized the dilemma students were faced with by her request to develop a recording system. While she has modeled various methods of recording data in previous lessons, the children were initially confused by having to "invent' their own method. Rachel

recognized this as an instructional opportunity to emphasize scientific processes associated with purposeful hands-on inquiry.

> Teacher: Hang on guys, maybe I'm not saying this correctly. As scientists, you're trying to find out what combinations in your circuit boxes make your circuits complete. If I'm looking at box J, how can I record my data? In your notebook, show me how you plan to record your data. (ATTENTION, DIRECT, DIVERGENT, INSTRUCTION)
>
> [Teacher solicits possible recording methods from students such as a column for boxes and a column for combinations. Students are thinking about how they will record.]
>
> Teacher: Do columns, a box, or draw a picture. You're excited [. . .] and I'm glad to see that, but as good scientists, you have to listen to me. You have to do the planning first. You don't have to tell [me] how you're going to figure it out. Tell me what you figured. (MOTIVATE, SUGGEST, DIRECTION) (Observation, October 22, 2002)

The planning itself becomes an important part of the lesson. Rachel did not endorse any one method, but left it open for students to figure out what would work for them. Learners did configure very different recording plans and each used their plans successfully. By allowing learners the time to plan, Rachel created active reflection in association with active hands-on learning. Students' recording designs were conceptual models for what they needed to do with the materials. The discussion that followed the hands-on investigation probed learners about how they collected and recorded their data.

Students' methods of recording represented their investigative strategies and revealed information about learning styles as well as content knowledge.

> Teacher: Can you answer [the question], What does your data table show? Who can tell me their strategy for finding out what combinations worked? (CONVERGENT)
>
> Student 1: I put wires in number one, then did one through eight, and then go to two and do one through eight.
>
> Teacher: Did you come to that strategy right away? (CONVERGENT)
>
> Student 2: We did something different. I didn't have to go back to one again, if you already did one.
>
> Teacher: Good. Tells me you can think in both directions. (ACCEPTS, RECOGNIZES) (Observation, October 22, 2002)

The quality of NHOT in Rachel's class served to enrich the HOT experiences of learners, while respecting learners' differences and preferences. This supports the notion that fourth-grade learners require scaffolding and direct instruction about inquiry.

Another aspect of Rachel's overall HOT practice was to actively monitor for learner frustration. Rachel attended to balancing learners' desires to solve problems on their own with the frustration that also comes from not seeing possible solutions or attaining a solution after multiple attempts to complete a task. In one lesson in particular, Rachel asked learners if they would like to know how to build a switch or if they would prefer trying to build one on their own. While learners initially wanted do it on their own, the teacher eventually showed them (20 minutes later) how to do it "the kit way," as learners were struggling with the task to the point of frustration. These sorts of

convergent interactions created divergent thinking opportunities later in the lesson. Once given a switch configuration, learners were able to appreciate their own thinking about their design attempts. After being shown the kit-switch design and trying to build it, a learner states, "Oh, I get it now. I should have done it this way before. [Several "Ahhs!" are heard from students as I circulate the room.]" (Observation, 11/12/02).

Rachel's instruction demonstrates the importance of valuing learners' self-assessment in relation to inquiry tasks. But her actions also illustrate that teachers will ultimately rely upon their knowledge of the nature of the learner when making instructional decisions.

Engages in Scientifically Oriented Questions

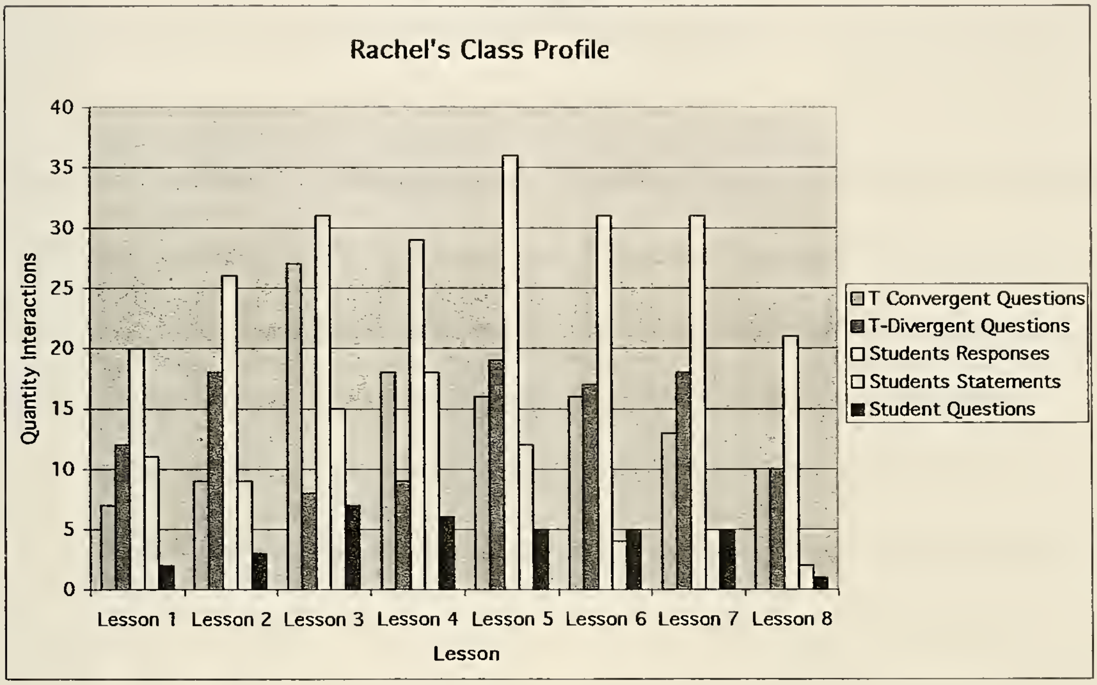
Assertion One (AR1): Students select among questions and pose new questions. Students in Rachel's class engaged in scientifically oriented questions posed by the teacher, the curriculum, themselves, and other learners.

In the pre-observation interview, Rachel stated the importance of questioning to facilitate science inquiry in learners. An analysis of Rachel's questions yielded a questioning profile that shows her use of convergent and divergent questions were, on average, evenly distributed across the observed unit lessons. There are two lessons where the use of convergent questions exceeded divergent questions. In Lesson 3, three times more convergent questions were asked than divergent questions and in Lesson 4 twice as many convergent questions were asked than divergent questions.

An analysis of the nature of those questions demonstrates a great deal of attention to defining terms, describing, and explaining in relation to what was flowing in the circuit. In Lessons 3 and 4, students practiced describing the flow of electricity through the circuit and its components. In Lesson 3, for example, Rachel lectured, demonstrated,

and employed lecture/discussion for approximately 27 minutes before transitioning to the planned investigation.

Figure 18.
Title: Rachel's Whole Class Profile.



During whole class time, Rachel focused on getting learners to use such language as electrons, positive, and negative. In Lesson 4, learners were required to explore building circuits without specific direction from Rachel. Learners asked their own questions, handled materials in order to develop a response to their questions, and documented their findings. During the lesson, learners presented what they did and discovered, resulting in a good number of teacher-initiated convergent questions to extract explicit event-related statements, descriptions, use of the target vocabulary, and to manage the setting during small group preparations to present their findings.

Rachel's use of convergent questioning, therefore, facilitated students' efforts to communicate science ideas and knowledge. The questions were used to assess the

attainment, not only of vocabulary, but also of conceptual understanding as a result of students' independent investigations.

While the kit-based curriculum ultimately presents the overarching questions to be asked, Rachel allowed learners to formulate the "big science question" they would investigate for each lesson. Learners in Rachel's classroom were asked to propose the "big science question" of the day in most of the lessons observed. The method employed by Rachel was a form of concept attainment. By presenting learners with materials representative of a conceptual example, she would then allow learners to identify the concept(s) they would be exploring by formulating the question to be answered.

> Teacher: I'm going to give you additional materials. I'm going to give you one of these [holds a bag of wires up], a battery holder, and one of these bulb holders. What do you think the big question of the day is? Hands down. Everyone has a minute to think. [Minute is up.] Who can tell me [what] the big question of the day is? (INSTRUCTIONS, DIVERGENT)
>
> Student 1: Um, we have to find out how you're going to light a bulb with a battery holder, bulb, and bulb holder.
>
> Teacher: In your own words, [write] what is the big question of the day [Students writing in binders.] (DIRECTIONS) (Observation, October 8, 2002)

Rachel guided learners to assume responsibility for formulating scientifically oriented questions that could be empirically investigated and that were consistent with the curriculum goals. She emphasized the need for reflective thinking, conveying to learners the need to give careful consideration to how best to configure and use the science equipment by formulating an investigable question bounded by the resources at hand.

Teacher: Who wants to tell me their question? (CONVERGENT)

Student 1: How are we going to light a bulb with wires, bulbs, and a wire holder?

Student 2: How do you build a circuit?

Teacher: You took that from the Table of Contents. I want it in your own words. (CORRECT, INSTRUCT)

Student 3: How are we going to light a bulb using two wires, a battery, and a holder?

Teacher: Science staff draw or write a plan in words or pictures. [Use] quick sketches [for] how we're going to do it. Is there a right or wrong answer? No. It's a prediction. (ACCEPT, INFORM, CONVERGENT, INFORM) (Observation, October 8, 2002)

Once students have successfully formulated a question, they consider how to represent and communicate the question and possible answers to the question.

Priority Given to Evidence in Responding to Questions

Assertion Two (AR2): Learners determine what constitutes evidence and collects it. Given that learners were responsible for formulating the "big science question" within a lesson, the learners' approach to the question ultimately determined what evidence supported how that question was answered. The degree to which Rachel guided or supported what data to collect was connected to the formulated questions.

Students' circuits ultimately looked the same or very different at the end of an investigative attempt. Students used the physical evidence that the bulb was either lit or not lit to determine their relative success when answering the big science question. Rachel's questions probed learners to trace out the path of the current flow and explain

why and how it was that the bulb was either lit or not. When the bulb was not lit, students were encouraged to trouble shoot the circuit. They began to manipulate the physical variables to isolate the offending system component.

Formulates Explanations from Evidence

Assertion Three (AR3): Learners formulate explanations after summarizing evidence.

> Teacher: [There is] only one working battery. I would like [you] to think about this. If you had a light [bulb] that you need to light and stay lit for a long period of time, would you build your circuit in parallel or in series? Tell me why.
>
> (Observation, 10/29/02)

While this question was inherently convergent, the instructions to explain why made the extended response divergent. The question presented learners with a scenario that required them to extend their thinking from their hands-on discoveries with parallel and series circuits. The learners had to consider the evidence amassed from working with the series and parallel circuits in order to formulate a "correct" response and then provide a feasible explanation that was grounded in the investigative findings.

Connects Explanations to Scientific Knowledge

Assertion Four (AR4): Learners are directed toward areas and resources of scientific knowledge. At the beginning of each lesson, students were given their materials and told to build a complete circuit. At the end of the lessons, students were asked to make an incomplete circuit before storing their circuit materials. The use of this language rather than instructing students to "take the circuits apart" immersed the learners in the

conceptual constructs of electric flow and circuit design. Although subtle, the learner was being directed toward acquired sources of understanding that allowed the learner to interpret the instruction in a manner consistent with accepted scientific knowledge. More directly, however, learners in cooperative groups confirmed and verified the communal meaning of shared and unique science explorations. When one student's circuit failed, neighbors and team members immediately were asked for support or offered supportive suggestions and materials. Trouble shooting was not isolated to the individual, but was a task of each member of the scientific community, including Rachel. Rachel's questions reinforced the community culture of doing science by recognizing and modeling the same behaviors. When systems fail, thinking is required to resolve the reason for the failure.

Learners were expected to see themselves and others as first resources in the scientific process.

Communicates and Justifies Explanations

Assertion Five (AR5): Learners formed reasonable and logical arguments to communicate their explanations. Learners in Rachel's fourth-grade classroom are expected to communicate their actions and ideas to others through their science journal entries, product presentations, and verbal communication in the classroom. Throughout the unit, learners were required to describe and explain their experimental set-ups, what they observed, and what they did to trouble shoot a problem circuit. The fact that learners worked collaboratively supported the communication and development of their thinking about scientific processes and questions. Notebooks were used in Rachel's classroom to write questions, record predictions, document materials and equipment designs, record

data, respond to questions, and as a resource (e.g., Glossary, Table of Contents) during class discussions and formal assessments.

Figure 19.
Title: Student Science Notebook Entry of Written Assessment Performance.

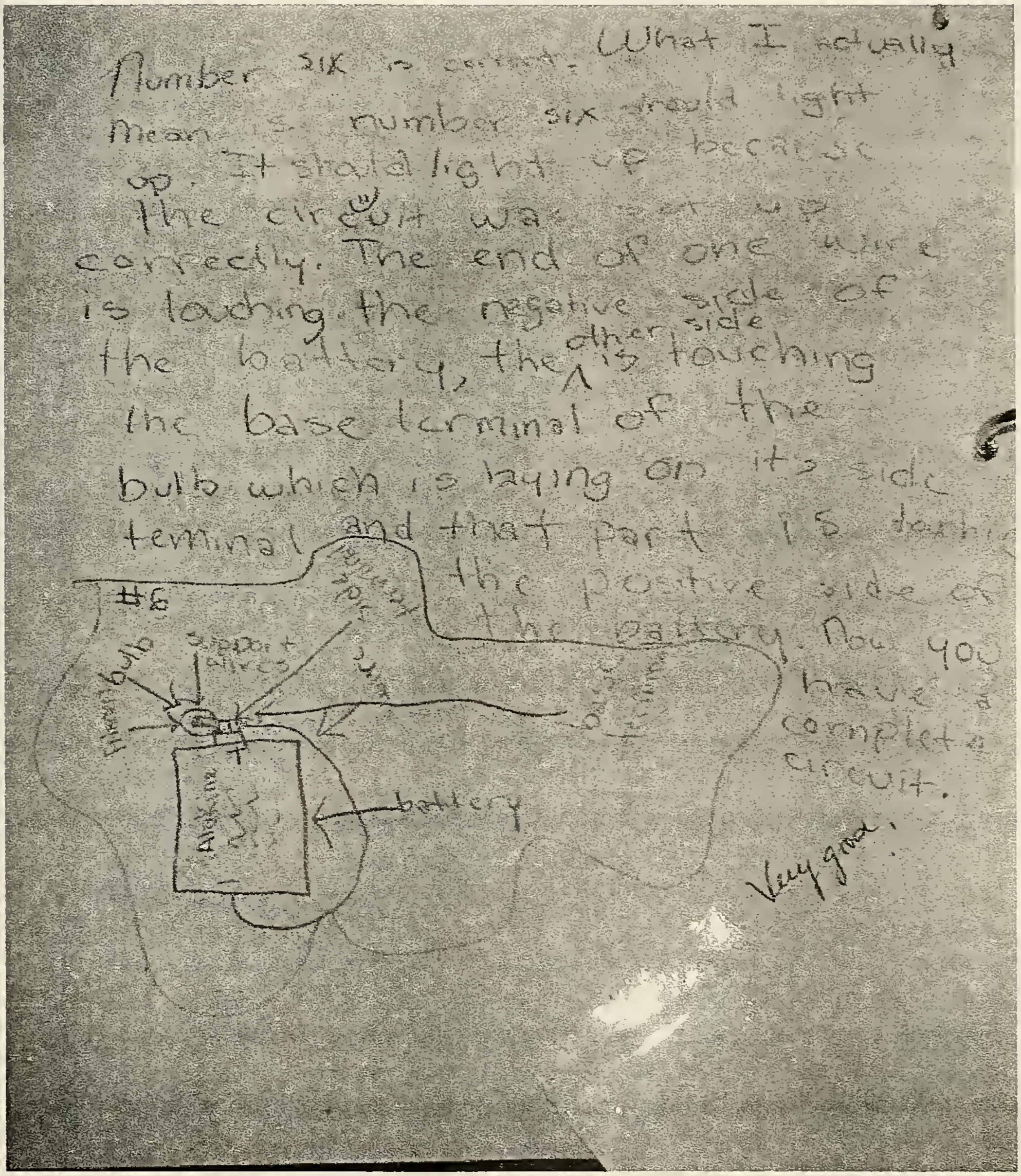


Figure 19 is a fourth-grade student's journal entry in response to an assessment question that asked if a certain circuit design is complete and will it light the bulb. The student described the response to the question by using both text and a labeled drawing. The

language used by the student was consistent with the vocabulary introduced over the course of the unit, and it is used appropriately.

Case Summary

The observed events in Rachel's classroom were consistent with what Rachel described in the pre-observation interview. Rachel planned for the use and distribution of materials to students working in cooperative groups. Students conducted investigations, talked about their science-related activities, and were generally excited to do so. Most lessons were not "open-ended explorations," but there was opportunity over the course of the unit for some open-ended exploration by learners.

Rachel had stated that "asking questions and determining how you're going to answer those questions" was part of inquiry. Scientifically meaningful questions were asked and answered in her classroom. Most of the questions were kit-based, and some were the result of learners' wonderings. It is the process of asking questions, however, that defines to what extent learners are actually engaged in inquiry around those scientific questions. HOT alone does not define inquiry. It is a component of inquiry that ultimately extends thinking about content knowledge.

The role of the teacher's questions was an important component of Rachel's thinking about science teaching and so played an important role in how learners experienced science in her classroom. The data supports Rachel's self-assessed position along the IC as one of guiding inquiry with a tendency toward directing the students as it is deemed necessary. However, within a given lesson Rachel transitioned along the IC as she moved from guiding toward being more open in her approach to elementary school science.

Turtle Lake Middle School: Tanya

Tanya has been teaching for nine years, and unlike the other teachers in this study, she teaches fifth-grade science in a middle school. Turtle Lake Middle School served nearly 800 students in grades five through eight. Teachers at the school worked in academic teams or clusters. Therefore, they shared a common group of learners and had a common planning period for team meetings. The school schedule was made up of 48-minute blocks or periods that were bell designated. Students passed to classes at the end of an instructional period. The school used a six-day rotation schedule, so students did not necessarily attend their content classes at the same time each day. The school's student population was 98% White, and 20% of the students was eligible for free or reduced lunch. Seventeen percent of the students received special education services. There were no students at the school receiving ESL or bilingual education.

Tanya held a masters degree in teaching and a Bachelor of Science degree in nursing. Therefore, she has taken a relatively large number of undergraduate and graduate science courses for an elementary school teacher. While she was not able to recall exactly how many hours of LSC PD she has completed, Tanya indicated on the background survey that the number of accumulated hours for LSC PD was between 200 and 249 hours. Tanya began kit training in the second to third year (academic year 1996–1997) of the LSC. Tanya had been teaching three science kits for the last six years, including the year of the study.

Tanya's middle school setting raised unusual challenges for the study. The setting was significantly different compared to the more traditional elementary school schedules at the other sites. She taught four sections (periods) of science and one section of social

studies daily for a total of 16 hours of science taught weekly. While it was not possible to observe the same class during each observational visit, four observations were made of one section and the other four observations were evenly split between two other classes. Care was taken to ensure that the same lesson was not observed in more than one class.

The three classes of students were different in their whole group interactions, but the mix of learning styles was evenly distributed across the classes. Each science section was an inclusion classroom, and teacher aides were present during most lessons.

Tanya's confidence in her ability to convey science to her students was marked in her manner and voice, and she introduced physical science concepts such as friction forces and kinetic and potential energies, which extended the conceptual goals of the designed unit. She respectfully referred to the students as boys and girls, and she maintained in her discourse a belief in students' ability to accomplish her instructional objectives.

The Curriculum Unit: Models and Design (FOSS)

The Models and Design module engages learners with science and engineering processes. Students must design conceptual and physical models as they explore the themes of structure, interaction, and system. Owing to the rotating schedule, it was not possible to observe all aspects of the four activities of the Models and Design modules. For example, while a review of student journals indicated some learners were engaged with activity four (Cart Tricks), the classroom observations were limited largely to events associated with activities one through three (black boxes, hum dingers, and go-carts). The Models and Design activities and goals were:

- Manipulate objects and materials

- Design and construct conceptual and physical models.
- Look for relationships between structure and function of materials and systems.
- Organize and analyze data from investigations with physical objects and systems.
- Apply mathematics in the context of science.
- Acquire vocabulary associated with engineering and technology.
- Gain confidence in their abilities to solve problems.
- Learn that there is often more than one solution to a problem.
- Communicate ideas to peers and work in a collaborative scientific manner.
- Use scientific thinking processes to conduct investigations and build explanations: observing, communicating, comparing, organizing, and relating. *(Models and Design Teacher Manual*)

Perceptions of Classroom Inquiry

Tanya described her perceptions of inquiry in the following manner: "Inquiry is really looking for the answers to questions; posing situations, questions, or problems; having kids offer a resolution; and explaining as they work through the [solutions]" (Pre-observation interview, July 11, 2002). The way Tanya described how inquiry would look in her classroom suggested that the children would conduct science investigations while she monitored the process and managed the materials and the learners.

> I will be setting things up and getting them [the children] ready to explore an idea or solve a problem. [For example, when using the kit] Models and Design, I give [the students] this bag and say, "How can you construct a cart to go two meters?" and set them loose. It takes two to three lessons to get to a point where they can be let loose. There are management issues [such as coordinating classroom

> activities]. In those types of lessons, once they are set free, I'm monitoring, walking around, and asking things like, "Why [do you think] that isn't working?" (Pre-observation interview, July 11, 2002)

Tanya had the belief that learners have to gradually assume responsibility for conducting open explorations. Thus, while the kits do provide the materials and content focus, there was some concern on her part about how much inquiry can reasonably be done that will lead to the formation of significant science ideas that teachers are responsible to teach according to the prescribed curriculum. This seemed to be an irresolvable, or at least troublesome, contradiction considering Tanya's understanding of the nature of science.

> [Inquiry] looks like wonderful fun, [but I] don't know [if] we have [time] available to let kids go wherever they want to go. We are more directed. . . . [The nature of science] is finding the answers to questions. Make observations, and don't jump to conclusions. [It is] asking questions and working through to find an answer that is correct. I understand getting kids to ask questions. I have a hard time seeing how that works with a kit that is prescribed. How do you do inquiry when given a curriculum? How to get to material [you have to teach] when [students'] questions may be totally off topic? (Pre-observation interview, July 11, 2002)

HOT

The fact that learners had science everyday in the fifth grade was a significant difference from other schools in this study where elementary students were situated. The percentage of HOT was comparable with other classrooms in this study. The amount of time Tanya had for science was not negotiable. In the traditional elementary school

setting some scheduling flexibility was possible, however, with a fixed time block rotation schedule, the middle school teacher could not simply extend time or alter students' schedules. While Tanya had no more than 25 students in a given science section, she did have a total of approximately 90 students to whom she taught science over her four science sections. While each class was dynamically different due to a host of factors, Tanya attempted to ensure similar experiences and opportunities across her sections during hands-on time. Equity was important because she had students with special learning needs in all of her inclusion classes.

Figure 20.
Title: Use of Classroom Time .

Total Minutes Observed	% HOT	Average Number of Minutes Observed/Class
359	36	45

The majority of Tanya's lessons began with a review of previous lessons or a discussion about what learners were to do and investigate. Tanya used a lecture-discussion approach facilitated by the use of the overhead projector or notes on the blackboard that were prepared in advance of class for the different classes over the course of the day.

The Models and Design unit focuses on science and engineering processes. The activities were designed to have learners solve engineering design problems to invent unique configurations given a predetermined set of materials. The unit inquiries had an engineering focus. Questions that were generated by learners were unique to what learners tried to do with the materials, which varied from group to group.

Because learners at the fifth-grade level were expected to work collaboratively using one set of materials, there was little opportunity to observe students working individually on a consistent basis, except for their notebook entries. The social development challenges for the fifth graders were to establish consensus and share in the handling of materials during HOT. Therefore, not all students engaged in the materials at the same time. On average, 16.2 minutes per lesson were dedicated to hands-on activities. This meant that on average each of the four members of a team had four minutes each within a given lesson to handle the materials. Despite having more minutes per week of science, the structure of those minutes posed an imposition to establishing continuity or flow to the hands-on process. Some lesson sessions allowed more hands-on time than others, but there were also lessons in which no time was given to hands-on activity.

Students were introduced to the lesson objectives, which were reviewed before learners proceeded with the hands-on activities. Directions were given and then students were reminded to focus on the assigned tasks. The person responsible for getting the binders (students' notebooks) and group materials did so, and the students began their design and construction of the engineering challenges.

During HOT, students negotiated the process of designing a physical model that met the pre-established functional criteria. Students tried a variety of things using ideas they generated. Each group met with different levels of success over the course of the unit and the specific tasks. As students worked, Tanya and any other adults present monitored students' efforts by moving among the groups. In one lesson, students were expected to complete their construction of a working humdinger. The teacher invited learners who had not completely resolved the challenges to examine her model for ideas.

This mediated student frustrations as well as ensured success for those learners who needed to see a working model to recognize or analyze feasible solutions, and it also affirmed the working designs of other students who attained some measure of success with their inventions.

> Teacher: My humdinger is out. . . . [If you need] more ideas, take a look at my humdinger. In science I don't want you to get hung up on stealing someone else's ideas. Looking at another design can help you work it out. The important thing is understanding it, getting it to work. . . . Scientists share information; that is how we make progress.
>
> [Four students walk over to examine the teacher's humdinger. Other students are at tables in groups pulling materials out and beginning to build. Students in this class were observed a week ago. The groups have redesigned their approaches to the construction of the humdinger. Many of the groups have working systems that need refinement. One group of students has a unique and effective configuration. The teacher tells the class to go visit this group to see how they have configured their system.]
>
> Student 1: Oh, cool idea. Can I try? [Refers to pulling the string.]
>
> Student 2: Thank you. Thank you. I'd like to thank my mom. (Observation, September 26, 2002)

The data indicated that Tanya sought to establish an open environment and culture in her classroom that invited originality and the exchange of ideas around hands-on activities. The challenge to design was not a disguised mandate to get "the" design, but to come up

with "your" design or "a" viable engineering design. Students, therefore, were able to learn from each other's experiences.

As students completed their hands-on tasks, the teacher moved through the room inspecting and monitoring. Students who completed the task successfully were directed to begin the process of documentation in their notebooks.

> [Teacher moves from group to group staying as long as necessary to ask questions and make suggestions, or to redirect.] (Observation, September 26, 2002)

Post-HOT students were expected to hold conversations to discuss and revisit their hands-on activities in response to notebook entry requirements.

NHOT

During nonhands-on time, Tanya managed the students, facilitated students' journal entries, small group dialogues, or conducted whole class lectures. Journal entries were reviewed using a whole class lecture-discussion. Students were told where they were to make entries using a prescribed journal format. During the lecture-review portions of the lessons, Tanya documented learner contributions on an overhead for students to copy or verify in their journals. Unique journal contributions were made in a special section of the journal called the Line of Learning. Individual learners were asked to record any new thing that they had already recorded in their journals into the Line of Learning (LOL) section of their notebooks.

> Teacher: Important facts and details are on the overhead. I'm taking notes on what you tell me. If there is something that we put down here, if you have not included it in your conclusion, put it into your Line of Learning, but make sure it is your [work]. Take the ideas that are new and make them your own. Not a word-for-

word copy of what is on the overhead. Who can give me a fact or detail you learned? Scan your conclusion right now. (DESCRIBE, INSTRUCT, CONVERGENT) (Observation, September 30, 2002)

Lessons were organized around Tanya's objectives, which were placed on the blackboard in the classroom. Assessments were formal and reviewed with learners before they did them. For example, lesson five was a review and preparation for the go-cart assessment. Tanya worked with learners to discuss what happened, what was learned, and how to prepare a well-written statement describing their efforts and findings. Little in the data reveals discussion that can be described as capturing divergent thinking by students. While divergent questions were asked, much of the discussion was centered on describing what various components were and how they worked.

Teacher: I need everybody paying attention. . . . Below the Line of Learning write there anything we discussed that you have in note form. Remember what you wrote and share one or two pieces of information you think is really important. What was important that you learned? (ATTENTION, INSTRUCTION, DIVERGENT)

Student 1: There is a small change from potential energy to kinetic energy.

Teacher: Potential is waiting to make something happen and kinetic energy is making something happen. [We need] more detail here. Where do we see potential energy on the cart? (DEFINE, DIVERGENT)

Student 2: Elastic.

Teacher: Potential energy is in the elastic. Can the elastic just be hanging? (RESTATE, ACCEPT, CONVERGENT)

Student 2: No.

Teacher: Elastic has to be stretched. (FACTUAL) (Observation, November 4, 2002)

The exchange illustrates that the teacher did not always probe the learner to expand on responses, but the discussion was to verify existing understanding. A good number of the convergent questions asked by Tanya elicited from learners what they knew, did, and definitions of science vocabulary. As an instructional and content modification to the basic kit design, Tanya introduced kinetic and potential energies. She believed that students could handle the extended concepts based on their experiences during the unit and the go-cart activity.

As already stated, Tanya used a lecture approach to establish the nature of the activity, disseminate information, and activate learners' prior knowledge relative to the instructional goals.

Teacher: When you hear the word "cart," what comes to mind? What characteristics would it have to have? (DIVERGENT)

Student 1: Four wheels.

Teacher: I hear other opinions? How many do you think it has to have? (DIVERGENT)

Student 2: Four

Student 3: Can it be anything more than four?

Teacher: [Can there be] less than four? (CONVERGENT)

Student 4: Three.

Teacher: [Can there be] less than three and really have a cart?

Students: No.

[Teacher puts four wheels on the table.]

Teacher: Do I have a cart? [Eight hands go up] (CONVERGENT)

Student 5: [Need] the rest of the cart.

Student 6: A body.

Student 7: An axle. . . . Something that makes wheels move at the same time.

[Teacher repeats and shows how to attach wheels.] (ACCEPTS, DEMO)

(Observation, October 7, 2002)

The above scenario illustrates how Tanya used her questions to promote the pre-assessment of learners' knowledge or understanding of "cart" and then to initiate thinking about the task to design and build a go-cart. Those learners who need some starting structure have been given visual and verbal "hints" to begin the process. Emphasis was given to the explanation of the physical models. Tanya established the expectation that learners would not only document what they did and their observations, but they would also have to explain how their inventions worked.

[Teacher asks what bearings are for.] (CONVERGENT)

Student 1: Keeps cart together, lets the wheels turn.

Teacher: What does the axle do? (CONVERGENT)

Student 2: Connects the bearings.

Teacher: What? (CONVERGENT)

Student 2: Connects to the bearings. (Observation, October 21, 2002)

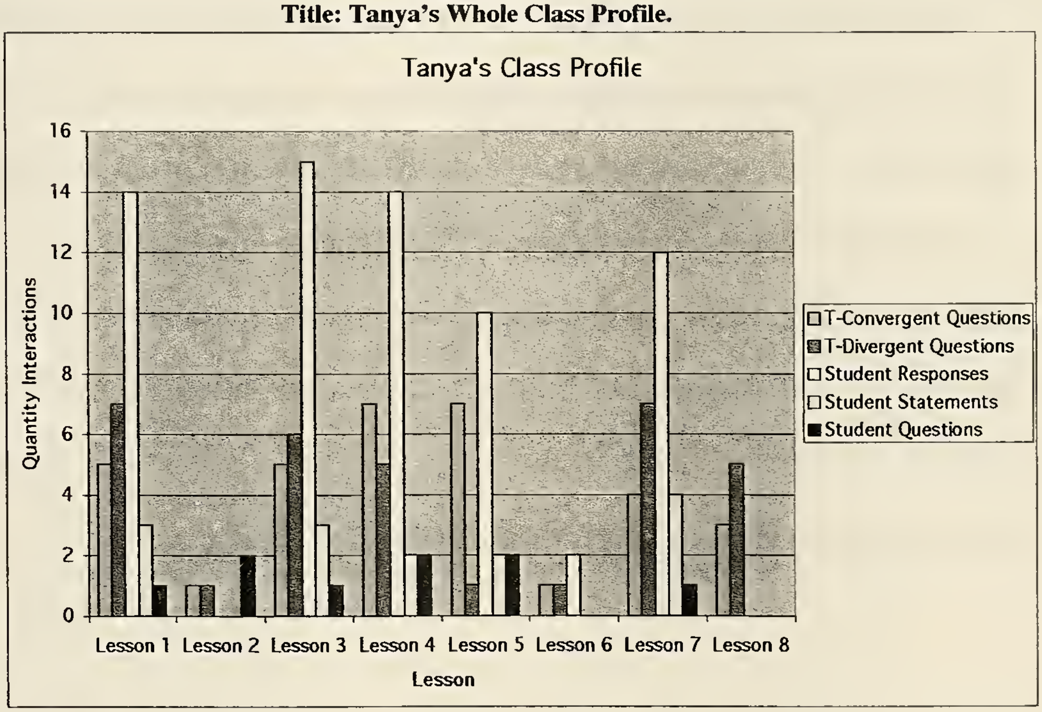
The student was expected to think through what was done, the vocabulary associated with the tasks and purposes of the physical model components, and recognize how the

individual components contributed to the overall product. In so doing, students were identifying systems, structures, and interactive components; a goal of the intended curriculum.

Scientifically Oriented Questions

Assertion One (AT1): Learners engaged in questions provided by the teacher, materials, or other sources. The evidence supports the notion that learners responded to the questions provided by the teacher and the unit. Teacher questions were evenly mixed between convergent and divergent questions. As already discussed, the use of these questions were not designed beyond the immediate engineering tasks of the unit. A review of selected student journals demonstrate an emphasis on what was done and what was successful in meeting the engineering goals. There is no evidence of deeper or extended investigations and questions.

Figure 21.
Title: Tanya's Whole Class Profile.



Another important aspect of the teacher's nonhands-on teaching goals was to get students to think critically about the language they used to label and discuss their models. Students were directed to use the material name to label the drawings and to use the component, or part name, when describing structures in their systems.

> Teacher: When labeling, use a short line and then the word. It is hard to write when you label and lines going all over the place. When I label my wheel and axle and bearing, I have to think about these things. On the inventory slip, is there a part named the axle or named the bearing? You have to think about what you used. So think about what part you used and make sure those are labeled.
>
> (Observation, October 21, 2002)

Tanya actively modeled as she lectured learners about the differences between what something is and what something does. Her strategy can be described as a modified approach to concept attainment. She first drew the learners' attention to the binder clip in the context of its system function, which was to act like a bearing. She then defines function. In this instance, the concept attainment model was abandoned to disseminate rather than to probe as to the concept function. Given that this exchange was associated with writing a journal entry, there may have been a greater focus on completing the writing task than extending thinking about a science concept. Tanya and her colleagues decided to initiate a new writing component to the science curriculum based on a model that was introduced during a week-long summer professional development institute. The intention was to use a more focused approach to writing in the science journal to improve science learning and to improve writing.

Priority Given to Evidence

Assertion Two (AT2): Learners were directed to collect certain data. The approach to the unit was to provide learners with problems, materials, and the evidence of their efforts to show what worked in solving the design problem. Students were directed as to what they should record and to consider evidence of success. For example, a humdinger design works when the product hums and dings according to pre-established criteria (e.g., the string was pulled and released). The challenges of developing evidence were embedded in the design processes that students engaged in with each engineering task. Learners evaluated their technological solutions to the unit-provided challenges. However, it was not clear from the data that learners initiated their own solution processes to the challenges all of the time. For example, when posed with the humdinger challenge, the teacher directed the learners to "think back to fourth grade about the kit that used the idea of electricity" (Observation, September 19, 2002). There was no way to know what the learners would have tried on their own and used as evidence in responding to the questions, owing to the teacher's intervention so soon into the challenge. Learners did record their observations about what they tried and if it worked.

During the go-cart activity, the teacher encouraged the students to record their observations and what worked as well as what didn't work. Students collected observational data as evidence to evaluate their successfulness with their design efforts.

Formulates Explanations from Evidence

Assertion Three (AT3): Learners were guided in the process of formulating explanations from evidence. Tanya directed learners in the process of formulating explanations from their evidence about the causes of an effective design. This was

evident in the data during the go-cart activity. Tanya worked with students in whole classroom discussion to identify and resolve design problems.

Teacher: Okay. What didn't work? What was the problem? (DIVERGENT)

Student: When you tape the wheel on the stick and the cardboard wouldn't roll down the ramp.

Teacher: So. What was the problem? What couldn't happen? You taped the cardboard on. What was the problem? (DIVERGENT, RESTATE)

Student: Wheels won't roll.

Teacher: Wheels won't roll and has to roll together. (RESTATE, FACTUAL)

Student: When you attach anything to the axle or wheels, it won't be able to move. (Observation, October 7, 2002)

Students recorded their attempts and adjustments to their models. The entries in their science journals reveal what they observed and how they attempted to use that evidence to formulate explanations as to why something worked to improve the performance of the go-cart. "Today we succeeded in completing the two-meter challenge. We added traction to the wheels, and it worked" (Student journal entry, October 23, 2002). This sample journal entry illustrates that the learner attempted an approach to add traction to their wheels and was successful with the redesign. The entry does not elaborate upon why the traction made the go-cart work better.

Connects Explanations to Scientific Knowledge

Assertion Four (AT4): Learners were directed toward sources of scientific knowledge. Students were able to successfully compare their results against the results of others, the teacher's models or suggestions, and their own ideas over several iterations of

their engineering attempts. The strength and value of the debriefing at the end or beginning of each design session was that students reflected upon what they tried to do, documented the performance of their efforts, and were given support in considering alternative approaches. Students were encouraged to look at the efforts of others.

Communicates and Justifies Explanations

Assertion Five (AT5): Learners were coached in the development of logical explanations, which they communicated. Students maintained daily journals of their design efforts throughout the unit. They shared their products and designs verbally and visually by either including labeled drawings that were reasonably to scale or by presenting their physical product designs. Owing to the inclusiveness of the classroom, learners' abilities and experiences with communicating their ideas varied. Through the whole class debriefings, Tanya was able to scaffold learners requiring additional guidance and support with formulating and articulating their ideas. Teacher aides also worked with learners to formally organize learner thoughts and to sequence events.

The notebook system was newly implemented and tried during this study. Students and teachers were making adjustments between meeting the need to improve writing and the need to discuss and share ideas about science. In a post-observation e-mail, Tanya describes the challenge to time management in accomplishing these multiple goals.

> I have to say that I would have liked more feedback from the kids when we were discussing their conclusions. The science notebook format is new for all of us and we all need to get better at it. It's also difficult when you have to carry over something like that final writing piece to the beginning of a class period. There is

just so much that you have to review before you can get things moving again! The notebook does involve more writing than what I'm used to, and I have to adjust for that. (E-mail, September 30, 2002)

Case Summary

In Tanya's post-observation interview she indicated satisfaction with the instruction of the Models and Design unit. The way the students' journals were used was an innovation to her instruction of the unit. It was one that required learners to engage in more time writing than she anticipated. Overall, she found the unit was a very guided experience in inquiry but that an important goal of the unit was to convey to learners that science is fun and can be enjoyed. While the kits are prescriptive in the questions and materials, Tanya indicated that at this stage, the learners still "don't get" how to ask answerable or investigable questions. It is a skill that requires time to develop. "They don't understand: Where do I start? What do I need? What would I do?" (Post-observation interview, December 23, 2002).

Consistent with her belief about learner development with regard to inquiry, Tanya's practice was one of directing, guiding, and scaffolding learners. Her interpretation of how to instruct the kit was to provide guided to directed assistance to encourage practice with the processes of inquiry. Tanya wondered if students "had more sophisticated materials and choices [would they] get further" with their go-cart designs (Post-observation interview, December 23, 2002). Tanya also wondered about how much content learners were ready for compared to the instructions provided in the teacher manual.

> One of the things I found [were] opportunities to expand with information not provided in the kit, like potential energy and kinetic energy. Learners use kinetic and potential energies with the elastic . . . too bad [it is not covered by the kit]. [A lot] of elementary students have that background [in physics], but the kit won't tell them [to include the physics] . . . It might be contrary [to think for them to] hear it at this level and understand [it]. And they understand . . . They get it. They truly do get it. So when they see it again . . . [they have] internalized the information and make it a part of what they know. [That is] not in the kit. (Post-observation interview, December 23, 2002)

Overall, Tanya stated that the observed learners' performances were "very much the same" as in prior years experience teaching the unit. The only difference was the added writing component. Tanya's practice was essentially consistent with her pre-observation description. Learners were set-up to solve engineering problems over the course of the unit. While the learners did not generate the initial questions or problems that they worked on during the unit, it was also Tanya's belief that learners need practice and guidance developing science questions that can be investigated.

West Haven Elementary School: Onna

Onna had 18 years of teaching experience. She was an English as a second language (ESL) teacher at an urban public school that served 350 students from kindergarten through the fifth grade. The school's student population was a diverse 74% White, 20% Black, 3% Hispanic, and 2% Asian and Native American. The student eligibility for free or reduced lunch was at 48%. Fifteen percent of the students at the school receive ESL or bilingual education. It was the most culturally and ethnically

diverse setting in the study. Onna's teaching assignment was to provide ESL instruction for grades one, two, and three learners. During the study, Onna taught science as part of a job-share position with a regular education, first-grade teacher. This meant that Onna was not the "regular" education teacher in the classroom. Onna's colleague had not taught the Balance and Motion unit before, so Onna was the Kit Specialist-mentor during the unit. Onna taught science between one and two hours a week and spent approximately 18 hours weekly teaching other core academic subjects. While Onna stated she was supported at her school to teach science, she did not feel that she had sufficient time to do so in her job-share situation.

Onna holds a mater's degree and took between seven and nine undergraduate and graduate science courses. Onna became involved with the LSC and began professional development in the first year of the LSC, 1994–1995. She had more than 250 hours of LSC PD, was a Kit Specialist, spent seven years teaching three kits, and had two years experience teaching another three.

West Haven Elementary School, where Onna taught, was situated in a middle-class urban neighborhood. Driveways separated the modest, single-family homes with small rectangular lawns. West Haven ES was a brick building, and like its immediate surroundings, it was a single-story building. There was no grass on the large fenced blacktop, playground where learners ran and played during lunch. This area was also where students went during a fire drill. During two observations, the principal held fire drills. The entrance of the school greeted visitors with a celebration of the diverse languages and cultures present in the school via hand-made tapestries suspended on the walls in the main entrance hallway outside the library. A comfortable sitting area had

photo albums of students and school events available for review by any interested guest. The researcher was introduced to the building principal and district superintendent on the initial visit to the site.

The 22 students in the first-grade classroom were talkative and active. Onna and her colleague often waited for the children to settle down in order to start or continue the lessons. The classroom was essentially divided into two sections: students' desks and a whole class rug area. The windows lined the external wall of the classroom. The rest of the walls were covered with teacher posters. A single computer on a cart with casters was situated at the rear of the classroom. The classroom was not Onna's but was the classroom of her colleague who assisted Onna during science.

The Curriculum Unit: Balance and Motion (FOSS)

The Balance and Motion unit began in September. It was not taught for the month of November but was resumed in December for two weeks. The reason for the month-long interruption of the science unit was to accommodate a grade-level social studies unit about Columbus and colonial America. The students' desks at the beginning of the study were arranged in groups of three to four. For the last three observations, the students' desks were arranged like two concentric horseshoes.

There were three unit activities scheduled for approximately 14 weeks. Due to the changes in the scheduling of the first grade curriculum, Onna did not complete the three curriculum activities, so approximately 60% of the unit was taught during the study. Change and Interaction were the principal science themes of the Balance and Motion unit (see Figure 22). Students observed objects and systems to discover how objects balance, and they also explored rotational motion. The first and last observations were kit

inventory lessons. These lessons involved the learners in an inventory of the materials at the beginning of the unit and again at the end of the unit.

Figure 22.
Title: Balance And Motion Activities Observed.

Activity	Part
1: Balance	1: Trick Crayfish—Taught *2: Triangle and Arch—Observed* *3: The Pencil Trick—Observed* 4: Mobiles—Not taught
2: Spinners	*1: Tops—Observed* 2: Zoomers—Not Taught *3: Twirlers—Observed*
3: Rollers	Not taught

Perceptions of Classroom Inquiry

Onna described inquiry as a process of

> Questioning, wondering, investigating, hands-on, active, mind engaging, probing, discovering, and "Aha." It is an exciting way of looking at the world, [it's] part of how I think. [I] facilitate. [I] don't lecture. [Inquiry] provides opportunities [for learners] to get excited about science and get down and dirty, to play and experiment, to use all senses and cognitive skills with real materials, [including] literature and music and poetry, conversations, [and] dialogue amongst themselves. (Pre-observation interview, September 17, 2002)

This view of inquiry suggested an instructional style that would encourage students to actively explore with materials and exchange in ideas and questions with each other and

the teacher. Onna felt that employing inquiry as an instructional approach requires her to let go and allow the "controlled chaos" that comes from having students engaged with materials have free rein.

Onna also recognized the need to be clear about "what the content is," otherwise young learners can become involved in playing and miss the content. At the early childhood level, Onna wanted learners to get excited about doing science and to have an "opportunity to begin thinking scientifically" (Pre-observation interview, September 17, 2002).

As an ESL specialist, Onna found that science can create success for the "neediest" learners and helps to level the performance field with "the Language Arts stars" (Pre-observation interview, September 17, 2002) in the classroom. The diversity of learners in her classroom reminded her that she was not there to tell but to listen and facilitate understanding.

The structure of Onna's lessons consisted of learners and teachers gathered at the rug area on the floor in the front of the room. The topic or challenge to be investigated was introduced through a process of review-based questions that required learners to describe what they did and talked about the last time they had science. This created a chance for Onna to survey learners, to sequence events, use descriptive language, and practice using learned science vocabulary while connecting it to things that the children did or discovered from the previous lessons.

Students were then given instructions in order to conduct the investigation, and the class was transitioned to individual investigations in small groups. Either the teachers distributed the materials or a student in each student group was selected for the task as a

[illegible]

"getter." During the individual, small group investigations, teachers would circulate the room and observe, ask questions of individual learners, or comment on learners' efforts. Except for the challenge provided by the teacher, there were no other formal questions that guided the children's explorations. In two of the five noninventory lessons, Onna closed the lessons by having learners report out what they did, what they saw, and what they thought.

Onna included literature in two lessons, along with demonstration and modeling. Demonstration and modeling were dispersed throughout the lessons. Instructions were provided to learners about what materials were to be used. In some lessons, students were told how the materials were to be handled, and students were expected to assume responsibility for their materials.

Students did not maintain a science journal or other documented form of their science. The entire unit was executed without the students formally recording information, ideas, and explanations. This meant that all of the learners and Onna had to recall their work and experiences from memory. Onna identified the lack of time, the building schedule, and the way the first-grade class was structured as challenges to her science teaching and the flow of the unit.

> I think that overall [teaching the science unit] went all right given the time constraints and the structure of that particular first grade. . . . I would like to have gotten more accomplished and more writing done, personally, [but] it is not my classroom, and also it was science on Monday and Tuesday, two days of the week. It sort of broke it up [that is], it didn't have the continuity and smoothness. . . . It [was] much less inquiry, less writing, and I did not get through the kit. We

met three times less the whole month of November. . . . for me it [teaching science] was frustrating in that sense. . . . (Post-observation interview, January 9, 2003)

Sessions did not always end with discussion or reflection with the learners about the lesson activities. In three of the seven lessons observed, when time was called, the lessons ended while learners were still involved with hands-on activities. The next teacher entered the room (e.g., the music teacher), and learners were either given a few more minutes to continue to investigate, or they were asked to put the science materials in their desks and get ready for the next teacher.

As Onna said in the post-observation interview, teaching science did not happen under optimum conditions due in part to many factors in the setting. However, despite these obvious challenges, she still indicated in the pre-observation survey that there was support in her school for science. From a historical perspective of elementary school science reform, her claim may be well justified since, science was formally present in the school curriculum as a nontextbook-based subject, and Onna existed in the setting as a science specialist who worked with other teachers to teach science. She ensured that students were learning important science processes. However, in many other regards, as already discussed, Onna did not fully realize her pre-observation description of classroom science inquiry. Yet, as the analysis of her instruction shows, many essential features of inquiry were present.

HOT

At an estimated 39%, Onna's learners experienced a higher percentage of their science time doing hands-on activities than any other classroom of learners observed in

the field study. Learners were actively engaged in observing the motion of objects in five of the seven documented lessons. During two of the lessons, learners inventoried the kit materials. While this was time handling the materials and gaining familiarity with the names of items, the inventories did not address a scientifically oriented question.

Figure 23.
Title: Use of Classroom Time .

Total Minutes Observed	% HOT	Average Number of Minutes Observed/Class
409	39	58

Of the three activities in the FOSS unit, one was completed in full, one was partially completed, and the last one was not completed. In accordance with notions of curriculum coverage (how much of the intended curriculum was presented by the teacher), Onna realized roughly 60% curriculum coverage. This study focused on what was covered and how the classroom teacher and the learners experienced the time.

The science teacher spent HOT with learners trying to answer or meet the motion challenges posed by the curriculum. The data indicates that Onna always demonstrated or modeled some aspect of the materials and their preparation for the children, but she did not indicate how to configure the materials to investigate the inquiry challenge. For example in Lesson 5, during the open exploration of tops, Onna had to show which side of the disk children should use to insert a straw for it to go through the opening, but she did not offer any suggestions or ideas about how the disk should be positioned on the straw or how many disks should be on the straw. The children working individually in their groups ultimately investigated multiple possible combinations of disks, disks positions, and how to get the tops to spin.

From time to time, Onna did support or scaffold learners by restating or emphasizing important concepts, definitions, and factual information. For example, Onna had a little rhyme-song that she taught the learners to help them remember how counterweights had to be positioned to ensure stability. There was nothing memorable about the tune to which the song was sung, but it proved to be an effective tool. The song was sung during the pencil investigation after learners had come to the realization that when the weights are positioned low relative to the object, the object tends to be stable or balanced. The song words were "Weights go below, way down low" (Observation, October 8, 2002). In the absence of maintaining a written record, the song became an auditory artifact of the scientific understanding that learners came to in order to explain why their inventions were stable.

Learners used their hands-on time to attempt to examine a scientific problem or question. Their activities served to generate a series of negative examples (what did not balance or spin) and examples (what did balance and spin) for consideration and explanation. Onna's questioning served to monitor learners' meanings and to motivate them to continue to explore.

NHOT

The time spent with learners when they were not engaged in hands-on activities was spent reading stories, using toys to illustrate important science concepts, and discussing the students' investigations in a lecture-discussion format on the rug area of the classroom. The fact that there was no written component to the unit meant that all communication was verbal and/or visual. Any reflection and analysis was conducted through talking and doing. The inclusion of storytelling added an alternative approach to

stimulating discussion and created alternative contexts for thinking about science topics and making connections between science concepts and the hands-on experiences of learners. Onna used a story to introduce the unit and the first activity in the unit.

> Teacher: [I want] to share a story about a girl on a tightrope. Who knows what a tight rope is?
>
> [Student 1 raises hand and is called on. A few seconds of wait time pass, but he doesn't know.]
>
> Student 2: A thing you walk on.
>
> [Teacher has asked students to raise hands, not to call out, so respondents are teacher-selected.]
>
> Teacher: Where do you see someone walking on a tightrope? In the playground, hospital, a zoo, a circus?
>
> [Students chorally respond to each suggested location with, "No, No, No, Yes." The teacher holds up and shows book's cover, reads the title and author: "Mirette on a High Wire by McCully." The teacher uses a "turn and talk" approach to examine pictures with learners, looking at pictures and turning to the students for their predictions and thoughts about what the pictures show or mean. The teacher begins to read the story aloud to the class.] (Observation, September 24, 2002)

The teacher used the reading of the story *Mirette on a High Wire* (McCully, 1993) to introduce the unit, the notion of balance, and the word balance during the discussion with learners. It was obvious that not all of the learners were familiar with the word, although they were familiar with the idea of trying to balance. This was an example of the students being presented with a positive example of the concept in the context of a story. The

concept was named by the teacher, but described through the story as interpreted by learners.

> Teacher: Raise your hand if you can walk across a high wire. On a balance beam? You'd have to use a special skill called balance [vocal emphasis added]. (DIRECT, SURVEY, INFORM)
>
> Student: What is balance?
>
> Teacher: That is a science word, and you're going to learn about balance. (INFORM) (Observation, September 24, 2002)

Other significant moments of NHOT were the inventory lessons. During the inventory lessons, students integrated mathematical ideas into the process of preparing for science. Students and teachers graphed the contents of the unit materials and also included making estimations. Students practiced important counting skills using multiples, which allowed them to practice their verbal communication skills and learn the English and/or scientific names of the equipment they were to use in their investigations.

> Teacher: See if you have a picture of what I am holding up on your paper. Plastic lids. Who might have this? What is the number next to that picture? We have to have 36 lids. Help me count. Count by twos. (Instruct, Divergent, Convergent, Instruct) (Observation, September 24, 2002)

The first-grade students chorally counted by twos until they reached 34 lids, and then the student responsible for documenting the count completed a graph showing how many lids were in the kit.

Like her colleagues, Onna's use of statements and questions directed learners through the process of making meaning of their experiences.

Scientifically Oriented Questions

Assertion One (AO1): Learner engages in questions provided by the teacher and materials. Onna provided learners with scientifically oriented questions from the unit.

> Teacher: [Holding an arch and triangle for learners to see.] Let's call it an arch. I'd like you to be thinking about how you would balance this: In your brain, you're thinking, how will you balance this triangle? How you will balance this arch? Think about what we had to do to balance the crayfish and what we had to do to balance Ernest [high-wire bear on a unicycle]. Today, rather than use your finger, you'll use a Popsicle stick. (DESCRIBE, DIVERGENT, DIRECT) (Observation, October 1, 2002)

Once learners began their investigations to answer the questions, they were more focused on showing what they had done and accomplished with the materials. Onna, the regular classroom teacher, and the researcher moved among the students to observe their efforts, and on occasion questioned learners about what they were doing. As learners accomplished the challenge, Onna would extend the challenge.

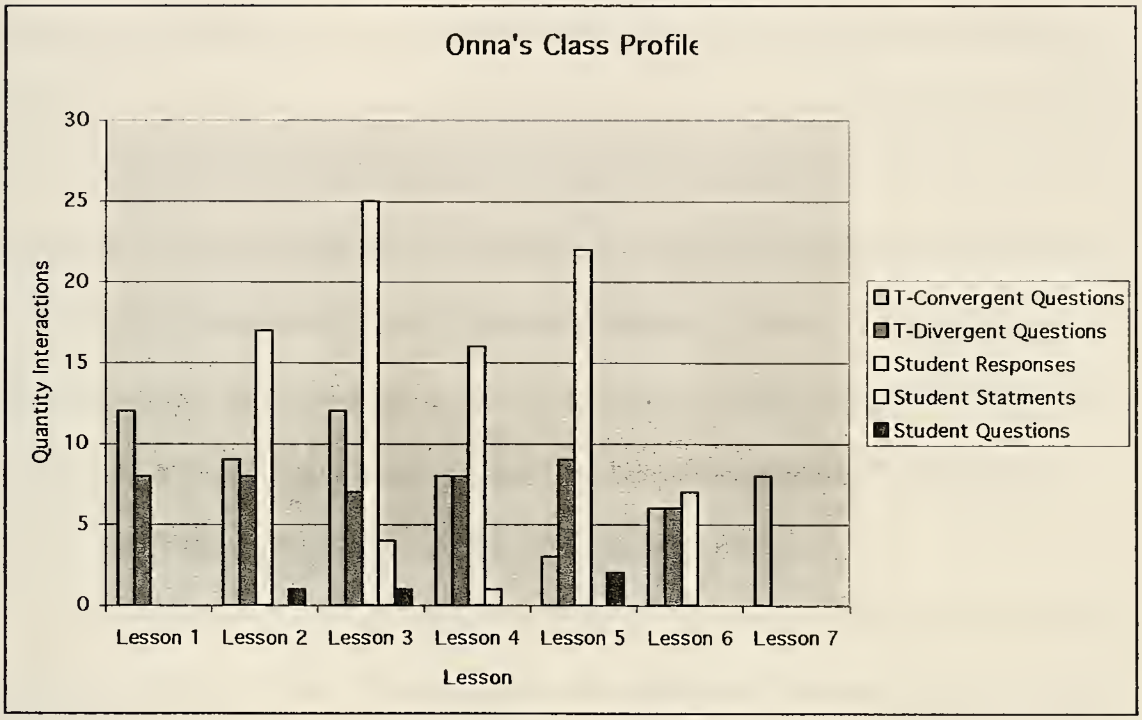
> Teacher: If you have balanced your arch with two clothespins, try it with one. (Observation, October 1, 2002)

While the questioning profile for Onna indicates that she asked more convergent questions than divergent questions, this was due in part to the lack of written documentation for learners to use to reflect on their thinking and activities. Often she used a lot of declarative directing statements coupled with convergent questioning as an accommodation for reflecting on previous activities.

> Teacher: Put your heads down while waiting for the rest of our group. Picture in your head what you did yesterday. Close your eyes and picture what you did to get your pencil to balance. What is the Popsicle stick? What do we call that? (MANAGE, DIRECT, CONVERGENT) (Observation, October 8, 2002)

The convergent questions were used to review students' understanding of the events they observed and to reinforce science vocabulary. Students were not often asked what questions they had, and the researcher documented few questions from children. If learners had questions they were often embedded in their hands-on activities as emergent wonderings associated with their trial-and-error attempts at completing the various tasks and challenges. Learners asked questions about materials. For example, during one lesson, students needed assistance wrapping aluminum wire around pencils. As teachers moved around the room, several students also asked the researcher if the wire could be tightened further, because their hands could not make the wire stay in place on the pencil. Other questions dealt with language they had not heard before, such as what to call the items in the kit or what "tushie" meant.

Figure 24.
Title: Onna's Whole Class Profile.



Priority Given to Evidence

Assertion Two (AO2): Learners were directed to collect certain evidence. This assertion is grounded in the fact that learners were told to try to achieve a goal, and as individuals, they made observations of events and used those observations to self-assess the attainment of the goals. Learners worked as individuals in small groups of three to six for most of the lessons. They were free to work at their desks or any place else in the classroom appropriate to their efforts. Students often shared what they were doing, and therefore, they shared ideas as well. This was not necessarily by direct verbal communication. Students often stopped to look at each other's configurations for ideas. Evidence consisted of learners observing the degree of success they had in achieving the investigative challenge. For first graders, if they were able to make enough adjustments

to get an object or system of objects to balance or rotate, then they had a system that worked. A working system was its own evidence. Students repeated their successes multiple times and made adjustments as time allowed. These repeated observations were consistent with scientific practice for collecting empirical evidence. The trial-and-error approach as a logical problem-solving strategy for gathering evidence was consistent with the developmental abilities of these early childhood learners. By engaging in multiple attempts either to confirm a previous effort or to improve upon previous efforts, learners were engaging in a process to improve upon existing or current empirical knowledge (Bereiter, Scardamalia, Cassels, & Hewitt, 1997).

Onna's discussions with learners led them to reflect upon what they observed with their senses regarding what was responsible for making the systems work, such as the role of the Popsicle stick, the role of the clothespins, and the role of the wires, or straws. This served to guide learners as they formulated explanations from the evidence.

Formulates Explanations from Evidence

Assertion Three (AO3): Learners were guided in the process of formulating explanations from evidence.

Teacher: What is the purpose of the wire?

Student 1: Balance wire on the balance point.

Teacher: What is the job of the wire? What do you have attached to the wire?

Student 2: Clothespins.

Teacher: Clothespins are . . .

[Whole class chorally]: … the weight. (Observation, October 8, 2002)

Students connected their observations with current understandings about balance and motion. Onna used a high-wire bear named Ernest in association with the story *Mirette on a High Wire* (McCully, 1993). The students introduced a wire and two clothespins to balance a pencil on a Popsicle stick balance point. Students were able to extend their thinking to connect the balancing pencil trick design to the information from the story along with the Ernest (the balancing toy bear) demonstrations. When Onna later introduced a balancing fisherman toy, students extend their thinking even further by recognizing that there was only a single fish "way down low" to balance the fisherman, but realized that the one fish is "like the clothespin" (Observation, October 8, 2002).

Onna also had students extend their thinking by using Ernest to get them to make predictions about what would cause the system not to balance (a nonexample of balance).

Teacher: What would happen to Ernest, if he turned upside down?

(DIVERGENT)

Student 1: He [will] fall and hit his head.

Teacher: Why? (DIVERGENT)

Student 2: Has to be below. [Refers to counterweights.]

Teacher: Below what? (DIVERGENT)

Students: The rope.

Student 3: Or he'll fall. (Observation, October 1, 2002)

Learners that responded displayed connecting different sources of evidence as supportive of their explanations. In this case, balancing objects remain stable if there were counterweights to keep them stable. This also demonstrated successful instruction and learning of a curricular objective.

Connects Explanations to Scientific Knowledge

Assertion Four (AO4): Learners are guided to connect explanations to scientific knowledge. Possible connections to scientific knowledge were suggested to learners as illustrated in the above discussion. The teacher used multiple examples that served to provide learners with alternative sources for formulating ideas from their investigations. Onna accomplished this by employing toys and literature. Learners also confirmed their explanations by multiple repetitions during investigations, and they relied on their observations of the efforts of their classmates.

Communicates and Justifies Explanations

Assertion Five (AO5): Learners were coached in the development of verbal communication of science ideas. While all of the learners in the classroom spoke some English, they were not all native speakers of English. Onna intended to have learners maintain a science journal and she spent class time during the second observed lesson setting up the journals, but this part of the unit plan was not realized. Students communicated about their knowledge using verbal exchanges and through the actual products they built. During the hands-on time, learners always sought out the teachers, the researcher, and each other to show what they had accomplished or tried, and the level of success they had achieved. When learners were working, they discussed and shared their ideas and findings, which they did freely. Due to the research design and the nature of the setting, many of these exchanges could not be captured.

Case Summary

The case story of Onna illuminates the challenges that teachers face in schools.

> The fact the curriculum is so dense unless [it is] well integrated, [teachers] can't cover everything; [We need] more planning time. The teachers I work with each have 30 minutes every other week [for planning time.] (Post-observation interview, January 9, 2003)

Everything in the curriculum needs time, including science.

> Inquiry takes time. If I don't have time and I need to move through the steps, I'm more guided than other times. (Post-observation interview, January 9, 2003)

Onna worked within these externally imposed limits to ensure that learners had science included in their curriculum. Her science unit met with limited success in some respects, but in many other important ways it was very successful. Learners did learn important science concepts, they were engaged in hands-on investigations of scientific-oriented questions that they found interesting or relevant, and they developed new science vocabulary, while reinforcing their English-speaking skills and knowledge. Learners, to the extent they were observed in this study, developed or demonstrated an appreciation for science investigations. They were always enthusiastic to do science and everyone participated in the science lessons regardless of their language skills.

> I do try to always [do] a language check . . . I do try to monitor comprehension and to constantly give reinforcement [during the] development of vocabulary . . . [I create] repeated opportunities with vocabulary . . . Another accommodation [I make], is [to] try to give a lot of time for conversation. (Post-observation interview, January 9, 2003).

Onna accomplished her instructional goals by using variety in the materials she employed and her approach to facilitating inquiry when children worked with materials.

She was not able to complete the unit, but she taught for depth in the lessons she was able to teach successfully. Of the seven observed lessons, two were interrupted by fire drills, and the unit was interrupted for four weeks due to a transition to a school-wide social studies unit. Under these conditions, the value of and importance of hands-on exploration to science learning were reinforced. After more than a month without science, learners were able to recall and discuss what they did and learned in science.

> Teacher: For the month of November, we kind of put science aside for a little while so we could get ready for our play [to learn about the pilgrims]. So who remembers a couple of things that we did way back before we started our Thanksgiving study in science? (FOCUS, DIVERGENT)
>
> Student 1: The first day of school?
>
> Teacher: Not that far, just what we've been doing in science. (RECOGNIZE, DIRECT)
>
> Student 2: Twisting stuff.
>
> Student 3: Spinning.
>
> Teacher: What was spinning? (CONVERGENT)
>
> Student 4: Tops (CONVERGENT)
>
> Teacher: Not yet.
>
> Student 5: We balanced on that wire we had up top.
>
> Teacher: Who can tell me about balancing quickly? (DIVERGENT)
>
> Student 6: You have to put your arms out, unless you wiggle.
>
> Teacher: Arms help you to be more st—(REVIEW, SUGGEST)
>
> Students: Stable and steady.

Student 7: Balance point.

Teacher: Exactly. What do you need to have something balance? (ACCEPT, DIVERGENT)

Student 8: Popsicle stick. (Observation, December 2, 2002)

It is obvious from this informal assessment and whole-class review that learners were recalling what materials they used and what they did with those materials, but they were also able to recall the science vocabulary associated with those events. They were connecting conceptual awareness of what their systems did, and they are able to talk about them scientifically.

This data supports the conclusion that Onna's unit was delivered under less-than-optimum circumstances, but because Onna remained committed to child explorations, learners had the maximum possible time handling and investigating physical phenomena. These experiences provided a living record for constructing meaning from those shared experiences. The images of inquiry held by Onna did not match this particular teaching experience with this kit with this unique group of learners; yet Onna was considered by the researcher to have accomplished to varying degrees the essential features of classroom inquiry (National Research Council, 2000).

Hilltop Elementary School: Allison

Allison had been teaching for 15 years at the time of the study, and she taught second grade in a K–four suburban, public school with a student population of 325 students. Ninety-six percent of the students who attend the school were White. Allison had been engaged in substantial professional development as evidenced by the 32 post bachelor credits she had earned, and her role as a Kit Specialist. She completed five

college courses in science at the undergraduate and graduate levels. Allison began professional development in the LSC to teach second grade science in 1995. Since that time, she completed over 250 hours of LSC-provided professional development. Over the last seven years, she taught three kits: Insects (FOSS), Simple Machines, and Pebbles, Sand & Silt (FOSS).

Hilltop Elementary School, where Allison taught, was a brick building that had undergone renovation over the years. The building design was such that a portion of the multilevel school was at ground level, with the lower-level classrooms cut into a hill. Allison's below-ground-level classroom had windows on one wall that faced a grassy field. The room was bright with color and activity from the many teacher posters and student work on the walls of the classroom. The science kit sat prominently on a table at what might be called the rear of the room, next to a computer station in front of the coat closet. There were desks arranged in five groups of four. At the back of the room there was a rug area. A chair sat on the edge of the rug, so that the person seated in the chair could see everyone and everything in the room. A whiteboard easel was positioned near the chair. Immediately behind the chair was an Insect Center. The center had books about insects, as well as plastic models of insects and insect toys that covered the table surface. The books encircled a trifold poster board with a drawing of a cricket or grasshopper that illustrated the three body parts of the insect. Next to the main entrance of the room was a sink area. Papers, file folders, and textbooks covered a table in front of the teacher's desk, which was positioned in front of the only windows in the classroom. Next to the teacher's desk was a rattan love seat that faced away from the direction of the rug area toward another door that led to an adjacent classroom. The amount of paper and files requiring

storage seemed to overflow and created a crowded, close feeling to the otherwise pleasant classroom.

Once students and the adults occupied the room, it became difficult to move around, and there was no place to sit that afforded a vantage point for observing small-group interactions, unless students were absent from school/class.

There were three adults in the classroom, Allison, a teacher's aide, and a student teacher. All of the adults worked together during science lessons. All children were serviced as required by all of the adults present in the setting.

Allison's learners were energetic, talkative, and accepting of visitors to the classroom. They approached the researcher with comments and questions, and they seemed to like it when asked if the researcher could take a picture of what they were doing. The students were interested in the researcher's technology and asked questions about it during the first few observations.

Allison had a student who was repeating the second grade, and this child often offered information about lesson-related activities from his prior experiences with the kit. Allison allowed and encouraged him to be an "expert" advisor.

Allison's voice was firm, clear, and gentle. She referred to the learners as "boys and girls" when addressing them. Allison established cooperative teaching strategies to facilitate student interactions during group work. "Accountable talk" was allowed and respectful treatment of people and living things was emphasized, for example, they couldn't squish the insects.

According to her survey response, Allison taught science for approximately 1.3 hours per week, and she taught language arts for 10 hours per week and mathematics for

six hours per week. Allison felt that the 1.3 hours of science time per week was a sufficient amount of time to teach the required science curriculum, and that there was a sufficient amount of support at her school to teach science. The school was on a six-day rotation schedule.

The Curriculum Unit: Insects (FOSS)

Allison taught the FOSS Insects kit during the study. The unit has been designed to consist of six activities to be conducted over a 12-week period with first- and second-grade learners. The overarching theme for the unit was structure and change. In this study, lessons from the first three activities were observed: Mealworms, Wax Worms, and Milkweed Bugs. The challenges of working with living organisms are: (1) not knowing if they will arrive on time, (2) whether the organisms arrive in good or viable condition, and (3) not knowing if the organisms will thrive or remain viable for the intended duration of the unit. The developers of the curriculum expect learners to engage in small-group discourse while working as individuals for most of the lessons and hands-on activities. The curriculum design proposes to promote the following scientific thinking processes: observing, communicating, and organizing. “Students observe and compare insect structures and behaviors in different stages of the life cycle, discuss and record findings, and pose questions to be resolved” (*Insects Teacher Manual*).

There were difficulties on all fronts with the Insects unit. The unit began late compared to the other units in this study because the organisms had to be ordered in a timely manner after the kit was delivered and inventoried. During the unit, wax worms were not delivered as expected and this resulted in the expiration of the organisms. It was possible for the classroom teacher to obtain a small sample of wax worms from another

teacher in the district who was also teaching the unit at the same time. Another problem occurred during the unit when the milkweed bug eggs hatched, but the nymphs expired before achieving maturation. These experiences certainly created alternative learning opportunities for the students. The teacher incorporated a great deal of literature resources and time using Internet-based information with learners to extend and enrich the kit-based unit. For example, students took turns going to the library to conduct online searches of relevant topics. These "science experts" were then required to report their findings to the rest of the class, including sharing their online search process and experiences. The teacher used music resources as well to convey or reinforce science information to learners. The Insects iMovie features the students singing two of the insect songs they learned as part of the unit. (Refer to the CDs in Appendix A.)

The researcher observed less than half of the unit-related experiences over the six observations. This was not considered an anomaly. Units designed with organisms typically expect learners to have daily interactions with the habitats or organisms by observing their behavior patterns and growth or death over the course of the unit. This requires teachers to be able to make modifications and adaptations on a continual basis in relation to the planned or intended curriculum. Interestingly enough, when Allison was asked how she thought the unit went at the post-observation interview, she indicated that she thought it went well, and that the unit was delivered and received in a manner consistent with prior years teaching it. This response can be interpreted to mean that Allison has learned to make meaningful adaptations to the unit that still allowed learners to grasp the key science concepts and master the unit's intended target skills and

processes. The findings from interviews with Allison and the classroom observations support this interpretation.

Perceptions of Classroom Inquiry

When asked to describe or define inquiry in elementary school science, Allison offered the following:

> Define with children in [the] classroom to open their minds and discover things [and] . . . take ownership of their own learning; it is the art of asking questions. [For example], instead of doing the kit the way [it is] directed, they come up with [their] own investigations. (Pre-observation interview, October 5, 2002)

The sort of things that an observer could expect to see in her classroom during a science lesson suggested that Alison, like her colleagues, valued and respected students' inquisitiveness. The use of divergent questions by the teacher can promote divergent thinking and probe learners to consider new or different questions to ask and investigate.

> The kids are discussing [their] own observations and take a step further to name what they're wondering about: asking questions about what they're seeing in small groups. I try to get them to ask more questions, [and, on] a clipboard I have questions I can use to ask them; there are [generic] questions such as, What will happen next? Why something happened? (Pre-observation interview, October 5, 2002)

According to Allison's interpretation, she was working with the kit-based curriculum unit required by the district that best lends itself to the kind of inquiry she described.

> Out of the three [LSC] kits [I teach], Insects lends itself to inquiry, because there are more possibilities to say what would happen if. The other kits are more

> teacher directed, [and] they have to be to accomplish what they have to. (Pre-observation interview, October 5, 2002)

Allison was realistic about the accountability demands on learners and teachers. The push to establish set criteria places a strain on teachers to accept and encourage learners to explore the questions that are "off topic" yet relative to the established program goals.

Allison anticipated integrating reading, songs, and vocabulary into her lessons that would allow her and the students to extend the kit lessons in meaningful ways. "We're always researching different things using the Internet [and] encyclopedias" (Pre-observation interview, October 5, 2002)

The Insect Science Center in her classroom reflected the importance Allison placed on alternative resources as tools in the inquiry process.

Figure 25.
Title: Insect Center in Allison's Second-Grade Classroom

Classroom Observations

Six classroom observations were conducted at Hilltop Elementary School. These six observations revealed that Allison's science lessons were structured in a variety of ways for her second-grade students. The Insects unit began with a school grounds field trip in early September looking for insects. This ensured that learners had a chance to think about where insects live and can be found in the natural environment.

Some lessons began with Allison and the students at the rug discussing findings from previous investigations, ideas, questions, reading books about insects, or students sharing information retrieved from the Internet. The rug area in the classroom was a common place for learners and the teacher to sit and have whole-class discussions. The

rug area was where she accepted responses and recorded them on a white board for future reference, or students were called upon to share their journal entries.

Allison relied upon a lecture-discussion approach in her teaching to introduce topics and focus learners. Allison also relied upon a direct lecture approach in her teaching of science to complete specific worksheets, set up insect habitats, and to inform learners of their responsibilities during a lesson. In one lesson, in particular, she provided learners with a worksheet, which the students completed at her direction while she illustrated on an overhead. In another lesson, students sat in three reading circles around the room, which was referred to as a reading circus by Allison. Each adult—the teacher, student teacher, and classroom aide—sat with a group. Students and adults took turns reading aloud about the life cycles of insects. Once the lecture and lecture-discussion portion of the science session were completed, students transitioned to working in their cooperative groups, where they recorded journal entries and used their hand lens to observe the insects available in class at the time.

The Insects unit requires teachers to use a certain amount of direct instruction in order to ensure that habitats are properly erected and maintained over the course of the unit. This study captured the complexity and tensions of setting the stage for inquiry and conducting inquiry. Learners and teacher had to discuss the nature of investigating living things and the responsibility that such investigations bring for a successful and productive inquiry. Students were encouraged to touch and use all of their senses, except taste, to observe, but they were allowed to make that decision based on their comfort level. With the recently received insects in class, children were asked to consider what the various materials were that came with the insects, such as food and shelter.

Teacher: Today [you're] going to your seats, and I will come by and give you an insect on a paper plate. You can touch it. I would never give you anything to harm you. If you put it in your hand, it will tickle you. If you don't want to touch it, that's okay. Yes, it is alive [In response to student's question; there is a great deal of student reaction at the prospect of having live insects to handle.] Shh. There are rules. (INSTRUCT, FACT, MANAGE)

Student 1: Don't pull it apart.

Student 2: Don't squish it. (Observation, October 3, 2002)

Over time, learners acquired more knowledge of the insects they were observing, which informed their notions of respectful handling. One student understood that shaking the vial habitats of the insects could be harmful to them.

Student: I wish I were a caterpillar, except I wouldn't want a bird to eat me. If I was, I'd want to be the only one in the classroom, so I don't get shaked.

(Observation, October 17, 2002)

Students maintained science journals throughout the unit. Students recorded in their journals whatever they found interesting. Students tended to draw what they observed first, and then they wrote their comments, questions, or observations in their journals. Initially, their entries were a mix of realistic representations and the fancifulness of second graders' interpretations of insects. Over the course of the unit, students' drawings began to show more realistic characteristics, such as color and appropriate scale. Allison reinforced that scientists record what they actually see in their journals. She did this using questioning strategies rather than direct lecture. While working with learners to complete a worksheet on the anatomy of caterpillars the following exchange was documented:

Student: Can I color the diagram of the caterpillar?

Teacher: No. I'm afraid if you color it, we won't see all of the body parts. What color was the caterpillar? (INSTRUCT, CONVERGENT)

Students: Brown.

Teacher: Right. So, if we color it, will we see the parts? (CONVERGENT)

Students: No. (Observation, October 17, 2002)

Clearly, the learners wanted to color the diagram of the caterpillar. Allison recognizes a teachable opportunity to reinforce the purpose of the worksheet and the necessity of accurate documentation as part of doing scientific work. She effectively redirects learners to complete the task at hand.

The students' science journals document the various lessons and activities engaged in during the unit. Drawings by students were unique and reflect what the individual learners believe they saw. Allison suggested using a microscope to see the insects closer and resolve discrepancies reported by learners like the number of legs on a caterpillar. She proposed through questioning that learners look at more than one caterpillar. Allison relied on the use of convergent questions during an essentially didactic lesson to reinforce the purposes, ideas, and skills of scientific process. She also had students stop and reflect on why they were completing a given task, which in this instance was to learn the body parts of a caterpillar. Students had been observing the insect, and they were now learning the proper names and quantities of the insect's anatomical parts. When learners first began their observations of the caterpillar, there were some differences in the number of legs reported by students. Allison called the class to the rug to have them report out their observations.

[Teacher records the different numbers of legs that students counted.]

Teacher: Do you think all caterpillars have different numbers of legs? Maybe I can put more than one caterpillar under the microscope? Did anyone notice anything else about the structures? (CONVERGENT, DIVERGENT)

(Observation, October 10, 2002)

Allison accepted and recognized each reported value and documented all of the values given by the students. She posed questions to have learners begin to consider how the scientific process required additional data before students could come to any conclusions from their first and seemingly contradictory observations of caterpillar anatomy. She presented learners with a model for when and how to ask another question. She generated another wondering, and she left open the possibility that perhaps not all caterpillars have the same number of legs as well. The teacher also modeled a possibility for how to think about answering the question. While subtle to the learners, Allison was skillful in her repeated modeling of "how to do inquiry."

Allison encouraged student discussion as an important component for making sense out of the observation and research processes. Students were expected to rely on a variety of resources and sources to learn about insects. These resources helped to fuel whole-class discussion. General descriptive language as well as scientific language were developed and reinforced during classroom discussion. The teacher was able to pose clarifying and probing questions to assess learners' understandings. For example, students who had a chance to go to the computer lab explained what they did and shared what they learned about insects.

[Students and teacher at circle time discuss the computer-lab research.]

Student 1: We went to [the] computer [and there were] a couple of words on top. It said butterflies, insects, or something. We had to click on it, we went on, and there was all this stuff like a question, read it and it told you what everything was.

Teacher: Why go to the computer lab and do that? (DIVERGENT)

Student 2: Ours can't do that [meaning the classroom computer].

[. . .]

Teacher: When you get there, you're going to search for an answer. (DIRECT)

Student 3: How many legs on a caterpillar, since there are so many opinions? How many legs does a caterpillar have? Type it in and hit enter on the computer. Next things appears are Web sites you can choose from. (Observation, October 17, 2002)

Students' questions were recorded and answered using available resources. Time was given to discussing the questions, the process for finding the answers, and finally the answers were agreed upon by the learners, teacher, and external authoritarian sources.

The students interacted in small groups, pairs, and individually. Students were, at times, expected to work as a collaborative small group and at other times, work as individuals. Students worked together to set up the habitats of insects, such as the milkweed bugs. Observations of organisms tended to be done on an individual basis. Students' questions were encouraged, acknowledged, recorded, and answered during the course of the unit.

HOT

The hands-on time in the classroom was spent observing, building habitats, recording observations, discussing observations, and asking questions. Children's

responses and wondering were associated with what they saw. In Lesson 1, students' questions that resulted from their observations were written on index cards and posted in a "Wonderings" column. As they continued to observe and research insects, the students' questions were answered over the course of the unit

Figure 26
Title: Classroom Time

Total Minutes Observed	% HOT	Average Number of Minutes Observed/Class
264	27	44

Allison "seeded" the students' questions to either broaden students' thinking when they observed or to focus their observations and to connect their prior knowledge with the questions they asked.

> Teacher: As soon as you're done, come join us. Everything that people observe [I'll put] on one side and things we wonder [I'll] put on the other side {in front of the plastic card holder hung on the wall in the rug area]. [Teacher asks students to share what is on their cards about what they observed or noticed about the insects. One student says that the insects will turn into something else.]
>
> Teacher: How do you know what it will turn into? Did anything you observed today tell you it was going to turn into something? (DIVERGENT)
>
> Student: I knew from before. (Observation, October 3, 2002)

It is noteworthy that students who had a good deal of prior knowledge were at times relied upon to share that information as "experts."

The degree of time spent handling materials and content was not expected by the researcher to be as high as with other units given the nature of working with living things.

However, the absolute time with materials is less informative about inquiry activities and processes in the classroom. The hands-on experiences require extension with other experiences not captured by the HOT data. It is very difficult with the Insects unit to calculate any truly representative measure of hands-on time connected to scientifically oriented questions, which was the criteria used for calculating the percent HOT. Students' ongoing, daily contact with organisms, if documented, would increase the absolute value reported. Therefore, it is suggested that the 27% HOT in Figure 26 be viewed as the minimum amount of HOT.

NHOT

It was through the other nonhands-on research-related activities that learners built knowledge from their hands-on time with materials. The roll of questions and statements by the teacher during the nonhands-on time empowered the learners as researchers and disseminators of science knowledge. Convergent questioning by the teacher required learners to sort their knowledge and understanding.

Teacher: Raise your hand and tell us what you know about three-stage life cycle? (CONVERGENT)

Student 1: No chrysalis.

Teacher: Right. What do they have? (ACCEPT, CONVERGENT)

Student 1: Nymphs.

Teacher: Can someone tell me what that is? (CONVERGENT)

Student 2: Something that is not going to fly.

Student 3: They're still small babies but look like adults.

Teacher: Looks like a miniature version of the adult. When it emerges from the egg, it keeps growing and growing. Who can tell me about the four-stage life cycle? (RESTATE, FACT, DIVERGENT) (Observation, November 18, 2002)

This line of questioning established the basic knowledge needed by learners to ensure that their observations of changes to the insects were framed for interpretation. As the lecture/discussion continues, Allison prepared learners for a positive example of one of the life cycles as manifested by the milkweed bugs, employing a concept attainment model for the hands-on experience.

Teacher: Today we have something very exciting [and] so small. Our milkweed bugs have hatched out of the eggs. You have to tell if they are going through the three- or four-stage life cycle. How can you tell? (INSTRUCT, DIVERGENT) (Observation, November 18, 2002)

This divergent question focused the learners' as they transitioned to make their observations of the recently hatched milkweed bugs. The embedded science questions were: What am I looking at? What evidence is there in my observations to indicate a three- or four-stage life cycle? These were worthwhile, important, and interesting scientifically oriented questions for the learners. They had to rely upon their understanding of the concepts and associated vocabulary of life cycle, pupa, larvae, nymph, and adult, and they attempted to connect their understanding of science knowledge to ongoing observations. They had to seek evidence from the recently hatched insects.

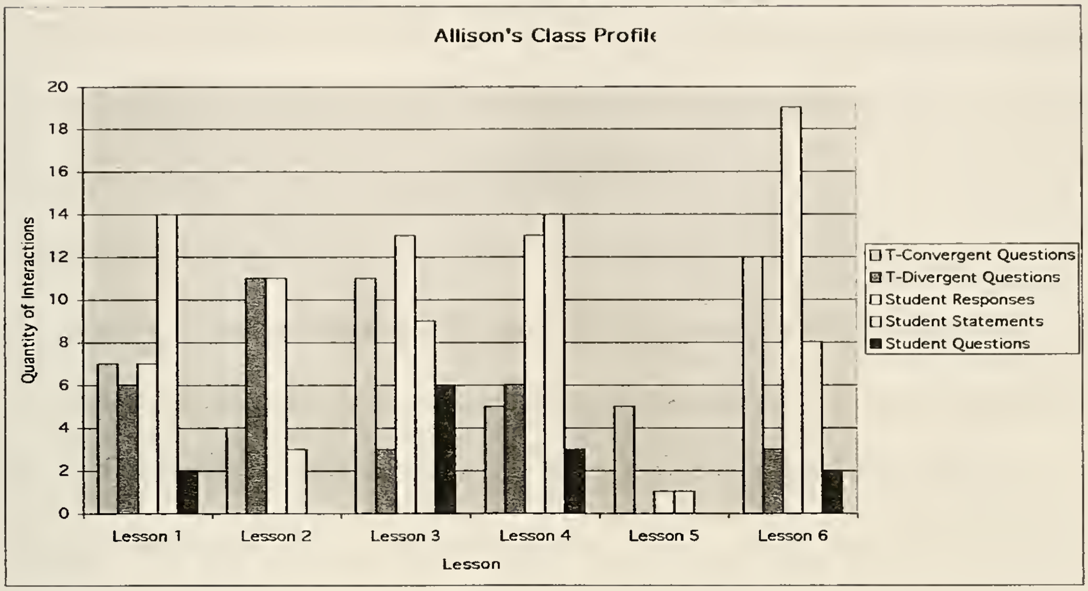
Allison, like her colleagues, structured her classroom inquiry using sequenced questioning across several instructional approaches within a given lesson that was

consistent with the teacher's guide. As students experienced it, inquiry was not bound by a fixed amount of time doing hands-on investigations. It was an open, ongoing process that moved learners to consider what the hands-on experience meant in relation to other experiences. Allison also required the use of external authorities for answering science-related questions. Students' questions were acknowledged during their contact and handling of materials and organisms, and opportunities were structured for learners to pursue answers to their questions.

Engages in Scientifically Oriented Questions

Assertion One (AA1): Learners select among questions and pose new questions. The data shows that learners were engaged in meaningful scientific questions that were as likely to be posed by the students as by the teacher. Students' questions were respected as important and necessary to answer through multiple approaches to research. The questioning profile for Allison illustrates that her use of questions varies depending upon the nature of the planned activities.

Figure 27.
Title: Allison's Whole-Class Profile.



The data from Allison's classroom suggests that Allison did not rely solely on the kit for her science. It was another resource—a valuable one—in her classroom for students as they investigated broadly the topic of insects. The kit clearly provided much-needed materials for learners to set up habitats that allowed them to directly observe specific organisms. However, the habitats were not authentic. They were made to ensure the survival of captive insects. Learners' hands-on experiences were not bound by the limits of what could be done with living things in a classroom. The questioning process for answering the big science question: What are insects, and what do they need to live? began with a field excursion in search of the insects that reside at school. The kit activities, then, were framed as another means of studying insects.

Priority Given to Evidence

Assertion Two (AA2): Learners determine and are directed to collect certain data. Students were free to decide what to look at when making observations of insects in their

habitats. The teacher often framed their observations with guided discussions or questions. For example, the teacher would ask students if they noticed any changes to the insect or the insect's habitat. While a subtle directive was what to collect as evidence, the questions certainly promoted learners to look for differences from previous observations. Subsequent teacher questions about what was observed required learners to consider what they saw and to connect those observations with a growing knowledge base. This is believed by the researcher to be an important difference in this setting. Collecting the data was one component in the process of building a meaningful knowledge base. Students' research of their questions employing other resources gave them additional information to integrate with their empirical evidence. While other teachers relied upon external resources to supplement their teaching, this setting had resources identified to supplement learning and to ensure that the teacher was not considered the sole authority in the classroom.

Formulate Explanations From Evidence

Assertion Three (AA3): Learners were guided in the process of formulating explanations from the evidence. The combination of observations, literature review, teacher questions, and scaffolding through lecture, encouraged learners to make connections between their prior knowledge of insects and the accumulated scientific evidence. Learners were encouraged to report findings that might be contrary to evidence reported by others and the differences were explored further. The fact that learners were encouraged to state and write what they thought or what they perceived meant that learners had to elaborate on their tangible products, such as their journal entries, through discussion.

Connects Explanations to Scientific Knowledge

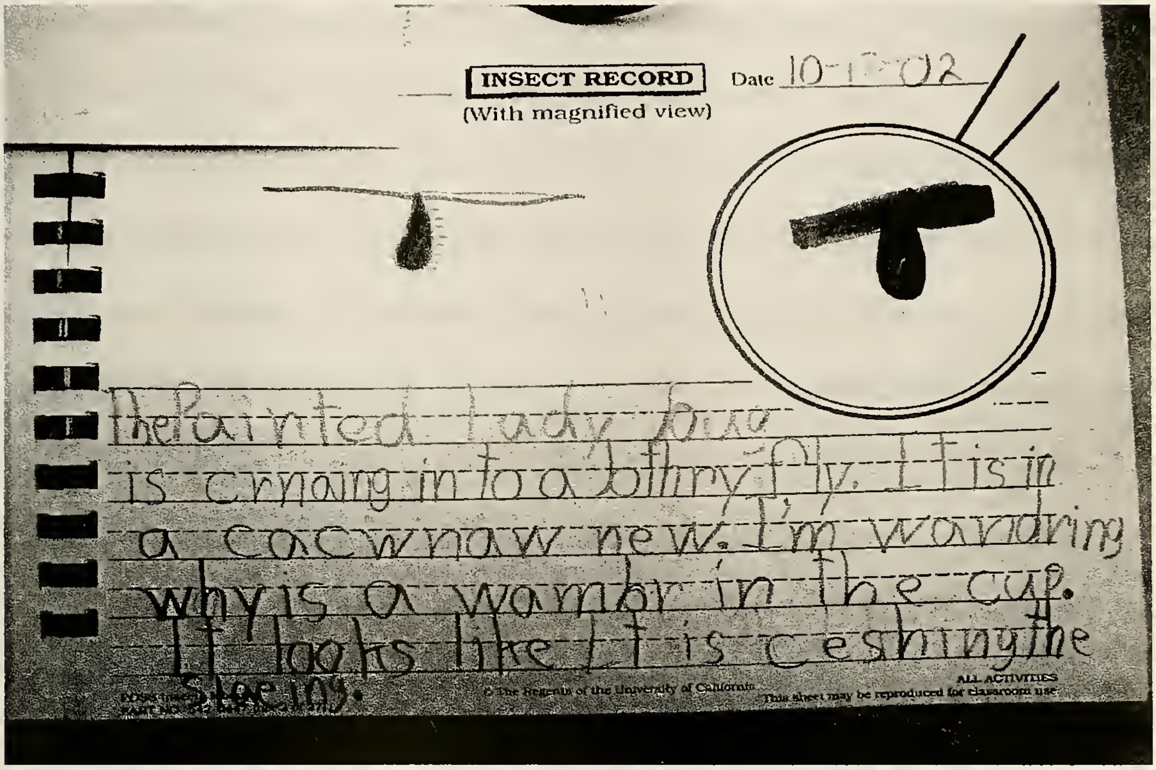
Assertion Four (AA4): Learners were directed to examine and independently examined alternative sources of scientific knowledge. There was considerable attention to learners' developing search skills, and considering alternative sources to support scientific explanations, or to formulate scientific explanations. For example, Allison recorded all of the differing numbers of caterpillar legs reported by students to let them see that there wasn't agreement from direct observation even when observation was aided with simple or more complex science tools, such as a microscope. The question, "How many legs does a caterpillar have?," required further exploration and resources. Students had to be disciplined enough as second graders to try multiple approaches and means to answer a question that they decided was important to answer. They had to trust in the research skills of others, and they had opportunity to look at multiple sources for confirmation of information obtained over the multiple sources.

Communicates and Justifies Explanations

Assertion Five (AA5): Learners formed and communicated reasonable explanations. Students shared and were encouraged to share their thinking and ideas within the small groups and in whole-class discussion. They posed questions and fielded questions and described procedures. They formally had to share explanations to questions that were their own as well as general questions posed by their class members and the teacher. They maintained a written record of their insect research in their science journals, completed anatomical worksheets, and sang songs as well (refer to Insects CD).

Figure 28.

Title: A Second-Grade Student's Notebook Entry of Observations of an Insect.



Case Summary

Allison's setting revealed how different content areas require alternative approaches and scaffolding of the inquiry process. She adequately described what the researcher would observe as inquiry in the Insects curriculum unit. Learners worked with materials, conducted observations, read factual books, searched answers to questions on the Internet, maintained science journals, and worked individually and in cooperative groups.

Allison indicated in the post-observation interview that the unit proceeded according to her basic plans. "I think it went well. [The students] learned the concepts" (Post-observation interview, December 20, 2002).

By teaching the kit with a "What would happen if?" approach, the teacher indicated that learners were able to have more ownership of the unit. They were designing questions and thinking about ways to answer the questions.

A challenge to inquiry processes was the nature of the kit according to Allison. It was very directed in how it was written. She countered this by not telling students what to do next but rather she tried to ask them what they think should be done next.

> [These] kits are very directed, more so than others. [The] Insects [kit] is extremely directed. The way [the kit manual] is written, you are presented with structured [lessons] and practice. . . . [I] try to move away from the kit [and] change some of the things [to more] open-ended "What do you think we need to do next?" and ask the kids for more information. (Post-observation interview, December 20, 2002)

The amount of comfort learners have with inquiry processes was dependent upon the background knowledge the learners brought with them, as well as their prior learning experiences, with inquiry from Allison's perspective. Allison believes that her instruction in science was a guided form of inquiry consistent with the development of her learners and the demands and structure of the curriculum unit she taught.

Chapter Summary

In this chapter, the results and events from each case-like study were presented and discussed. The degree to which the indicators or essential features of classroom science inquiry were present was also discussed in the form of assertions. These assertions were based on the analysis of the pre-observation interviews, classroom observations, post-observation data, student artifacts, and the curriculum unit goals.

The case-by-case analysis illustrated the variation in teaching approaches to inquiry-based science across grades one through five. Teachers utilized questioning strategies to extend inquiry processes and learner thinking. They also varied their approaches over the course of the unit and within individual lessons. These findings will be discussed in greater detail in the following chapter. While it was not elaborated upon extensively, the data for each teacher also illuminated ways that inquiry processes were compromised or not realized in each setting. Teachers, at times, did not either recognize or elected to not act upon "teachable moments" that may have furthered inquiry. The reasons for these decisions "in the moment of teaching" are complex. They were connected to factors within the setting under the control of teachers and factors in the setting imposed externally, which teachers couldn't control. One setting feature that teachers had control over, which was externally imposed, was the respective curriculum each teacher taught.

Teachers' views of the curriculum was that it frames the science concepts and skills to be taught and provided basic materials for hands-on experiences, but does not guarantee inquiry teaching and learning in elementary school science. The kit is a structured, generic tool for instruction that has to be interpreted by the teacher to ensure inquiry experiences for learners. Teachers using kits were challenged to move past the kit into a more meaningful interpretation of inquiry teaching.

The next chapter collects and collapses these findings into what was common and shared among the LSC teachers and addresses the broader cross-site questions of:

1. What are the answers to the research questions from an analysis of the cross-site data?

2. What, if anything, can be generalized from the case studies?

3. What cannot be generalized from the case studies?

Chapter 5

Cross Case Assertions

This chapter presents the cross-site or cross-case (Miles & Huberman, 1994) analysis and findings from the field study. A summary of the teacher case-study information will be presented. The assertions from Chapter 4 are organized and presented using the Inquiry Continuum and the Essential Features of Classroom Inquiry matrix (National Research Council, 2000).

ACC1: Teachers in this study used the adopted kit-based science curricula scheduled by the LSC Materials Resource Center to teach science. The materials were actively present in determining what science content was taught, what materials were made available for instruction and formed the basis of the science questions investigated in the different classrooms in the study. Two relevant ramifications emerged as a result of teachers using the kit-based materials: (1) teachers' time to teach the unit was impacted by the MRC schedule, and (2) the nature of the hands-on time activities was defined in part by the curricula.

Based on discussions with teachers, each teaches at least three kits that comprise the yearlong science curriculum at a given grade level. This suggests that a reformation effort to introduce and establish science into the core academics of elementary schools has been successful with the teachers in this study.

A common feature of science kit use shared by the teachers across the cases was that the kits had a predetermined date by which they had to be returned to the science Materials Resource Center (MRC). This had an impact on how teachers structured their

lessons and what modifications, if any, were made to the intended curricula in order to accommodate the mandatory return dates. While teachers made decisions based on what would facilitate science learning, they did so by accommodating and adhering to the return dates of their respective kits. It is not clear from this study, if teachers could have requested additional time with the materials. One teacher was willing to ask for additional time to accommodate the researcher, but this offer was declined in an effort to document the authentic challenges to materials availability and use. It is an assumption of the researcher that when teachers describe having enough time to teach science it was based on teachers having:

1. Accepted what the demands are for planning and preparing to use the kits.
2. Learned how to modify the unit lessons to accommodate a predetermined kit schedule set by the MRC.
3. Learned how to make modifications to the units to make science knowledge and inquiry more accessible to learners.

The use of the kits, while a reform goal, was not the only reform goal realized by their use. Kit-use provided teachers with an opportunity to attempt and experience inquiry. This was not necessarily a result of kit design. By having the materials and the teacher manual for logistical directions, teachers theoretically focused on teaching and interactions with learners. Interestingly enough, all of the teachers expressed concern about the limits of the kit-based science curriculum in achieving full or open inquiry. Each teacher interviewed referenced the kit they were teaching at the start of the year as the kit at that grade level best suited to the goals of achieving or developing learners' experience with open inquiry.

The amount of time learners spent actively engaged with materials was also consistent across the classrooms. Children on average were engaged with materials and actively using those materials for about one-third (34%) of the time during science instruction. The purpose of the hands-on activities varied within each unit. Drayton and Falk (2002) suggest that HOT activities can be of three types:

1. Activities that are used to convey content.
2. Activities that engage attention, raise questions, or change pace.
3. Activities that primarily illustrate content.

All three forms of activities were present in this study.

ACC2: Teachers recognized that there were limits to engaging in inquiry with the kit-based units. All of the teachers in the study suggested that the kits set prescribed limits on how much inquiry learners experience. Teachers sought to extend the amount and quality of inquiry experiences of learners by making adaptations to the kit-based lessons. Kit modifications were also made due to impositions by school-based decisions.

The kit-based units represent the required or mandated curriculum for science. The degree to which teachers are making modifications was mixed. The nature of documented modifications consisted of:

1. Combining or altering the sequence of lessons and activities.
2. Adding to, altering, or not using supplied materials.
3. Making adjustments to the directions provided in the teacher's manuals.
4. Integrating mathematics, literature, and computer technology as resources to supplement the science curriculum. (The "extensions" to the kits are advocated by the unit developers.)

Teachers sought to or achieved these modifications to varying degrees. Rachel used a computer program about electricity she obtained from an electric power company. Rachel has been trying to locate grade-appropriate reading materials other than electricity experiment books to use with the unit, but she has not been successful to date. She also combined lessons as well as including her own “mish-mash” review lesson. Allison used books and the Internet with her learners and learned from experience what to change in the basic instructions for setting up insect habitats. Tanya used an alternative assessment that extended learner thinking about energy. Students were asked to design a wind-powered cart. Natalie also supplemented the kit with additional assessment activities and taught kit lessons out of the prescribed sequence. Natalie also made an adjustment in her scheduled science lessons due to Parent Day at her school. The lesson on hard and soft water was taught out of the intended sequence and was “abbreviated” in order to ensure that students and parents could work on the investigation together.

The four teachers that utilized the FOSS kits achieved the curricular goals in relation to the target thinking processes. The figure below illustrates the intended curricular thinking processes as goals for each of the units taught in this study.

Figure 29.
Title: Target Thinking Processes of FOSS and STC Content Goal Matrices.

Unit	Observing	Communicating	Comparing	Organizing	Inferring	Applying
Bal. & Motion	x	x	x			
Insects	x	x	x	x		
Water	x	x	x			
Models	x	x	x	x		
Electric	x	x	x	x	x	x

Students were observed in each setting and grade level actively involved in science processes that included observing, commenting on their observations and the use of materials or tools related to the intended lesson or unit goals consistent with the above processes. The specific goals were dependent upon the content, the grade level, the social interactions and skills of students, and the teacher approach to classroom management. In all instances, teachers maintained an active awareness of student behaviors and interactions. Students were not seen wandering off, doing nonrelated activities, or having discussions that were not consistent or inappropriate to the learning objectives. As indicated in Figure 28, all of the students were engaged in the targeted processes in all classrooms over the course of unit instruction.

It is apparent from the target thinking and reasoning processes that the units have been designed for learners to accomplish certain identified processes based on grade or developmental level and content. This supports teachers' assertions and perceptions that the kits "limit inquiry," but it also suggests that developers expect learners to have increased experiences with inquiry over time across the horizontal and vertical (K–six spiral) curricula.

> In the early grades, students are invited to be inquirers of objects—their characteristics, their similarities and differences and how they change. As students move through the grades and learn more and more about a topic, their knowledge base grows progressively richer. [. . .] All STC investigations involve inquiry; some are guided and some are open-ended. Guiding inquiry is necessary for the development of fundamental knowledge and inquiry skills. Open inquiry makes use of that knowledge and those skills. (Lowery, 2002)

It is the belief of the researcher that teachers need to feel comfortable with the idea that they and the learners can go beyond the designed intentions of a given kit unit (Saul & Reardon, 1996). The kits, as static curricular documents, were designed for a set of circumstances that have changed with their adoption and use. The kits were originally designed to provide teachers who have had little prior experience with science and science inquiry with appropriate materials and accurate content. As teachers develop expertise in their knowledge of science and abilities with school science inquiry, teachers should feel comfortable that they possess the abilities to integrate modifications to the units that can challenge learners to experience greater integration of inquiry and science process thinking than designed by the kit.

The findings illustrate that teachers' modifications to the units did not detract from the intended outcomes of the units. These findings also raise questions about what type(s) of professional development exemplary teachers of kit-based science should receive to further their science instruction.

ACC3: Teachers in this study valued the principles of inquiry in teaching elementary school science. In the pre- and post-observation interviews, teachers articulated that employing an inquiry-focused teaching strategy was important for elementary learners to experience in their science learning. Teachers were clear about what features of inquiry would be present in their teaching of science. Common to all of the initial descriptions of inquiry by teachers was the importance of asking questions. Teachers indicated that question posing and answering questions coupled with hands-on investigations were essential features of classroom inquiry. Teachers were also clear

about the differences learner development can have on how inquiry is experienced in any given classroom.

The Physical Setting

To the extent possible, teachers created settings supportive of inquiry. With the exception of Onna (Onna did not have her own classroom, but came into a classroom as a specialist), teachers' classrooms had bins of books, computers, posters, and word walls or strings. Classrooms were arranged or rearranged to allow students to access and observe each other. Students worked in groups, and students were able to utilize the entire space of the classroom during investigations. For example, teacher-furniture (e.g., desk, chairs) was placed along the walls so the available space was open to learners. Windowsills, tables, and even the walls became places for students to put their set-ups and monitor their investigations. The Water unit required learners to use locations throughout the building to monitor changes in the evaporation rates of a fixed quantity of water over time, while a ceiling became useful to set-up the classroom word string that hung over the rug area in that classroom.

All of the classrooms except for one were crowded, and the researcher found it difficult to move around the classrooms during observations.

Social Interactions

Learners were able to discuss their actions, ask questions of each other, and share ideas. Classrooms had a "sustained hum" of productive student discourse focused on science-related activities. Students were free to move around and talk within their respective groups. They were also encouraged to share across groups and were free to

move around the room to observe what other students were doing. These interactions included social development skills such as sharing space and materials. Students had to accept alternative views about what to draw and how to express their ideas. This was a value-added aspect of maintaining notebooks, as students often referenced their notebooks when working with others or wanting to share what they saw and did. It is not known if this was an intentional activity on the part of teachers or not.

Student Questions

A principle of inquiry teaching consistent with a constructivist posture is that children are theory makers and bring to class with them all of their world views and experiences. When teachers seek to have children actively inquire, they are making an effort to change children's beliefs (Cobern, 1993). To do this, teachers relied upon students' verbal, visual, and kinesthetic performances—active performances—in the classroom to gain an understanding of what those worldviews were. The assessment process should have included allowing learners to ask their questions.

Yet teachers were able to honor learners' questions to greater and lesser degrees across the sites. Four of the five classroom teachers had a place where students' questions could be recorded, documented, or displayed such as in their notebooks or on a "wonderings" board or through some other advanced organizing process. There were other ways in which students' questions were actively recognized and engaged. For example, Allison and Rachel allowed for and incorporated more opportunity for research and exploration respectively. Tanya kept students' questions to a more group-specific level, as each go-cart or humdinger approach was unique and different. The same can also be said for learners working with Onna. Students' questions were focused on their

respective engineering decisions and attempts, as learners had to create their own responses to "How am I going to get this to work?" or "Why isn't this working?" So, while students may not have initiated investigations with their own questions, they did question throughout the process of conducting investigations. The attention to children's questions as an important part of the inquiry process was challenged in the instructional setting by the spatial and social configurations of the learning environment. When learners were in groups, they were localized and often their questions and comments were not necessarily common across the groups and were difficult to capture. Teachers monitored the groups, but over the course of the lesson, this amounted to a sampling of the individual and smaller group interactions and experiences.

Again, some part of good inquiry teaching does include teaching about inquiry. How teachers made that decision was based on knowledge of learners. Teachers do need to model questioning and inquiry skills and processes. But learning *about* inquiry and learning *to do* inquiry are very different instructional goals that teachers were aware of in their planning and teaching. Teachers dealt with both goals consistently throughout their teaching. Part of why teachers may be teaching about inquiry was that teachers are themselves continually learning about inquiry, but also they were assessing where learners were in their growing understanding and skills for *doing* inquiry.

Attitudes and Behaviors

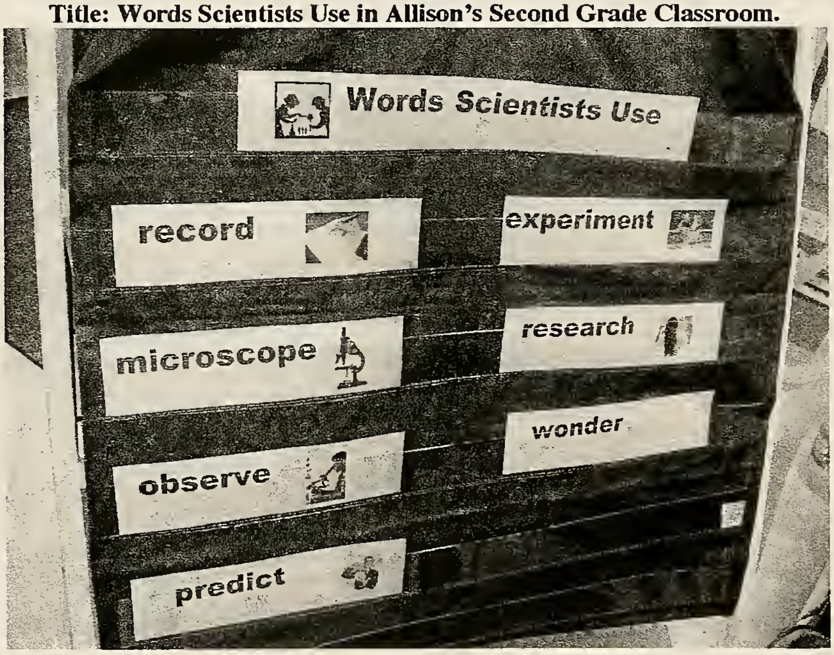
The researcher viewed references by teachers to what scientists do and acting "like-a-scientist" as indicators of teaching about scientific culture. For example, maintaining notebooks to keep a scientific record was an important like-a-scientist activity in four of the five of the classrooms. While Onna was not able to have learners

keep notebooks, she described in her post-observation interview that for her learners her science lessons were

> an opportunity for students to begin thinking scientifically, see in the first lesson what scientists do. At the beginning of each kit, I make a big deal [about how the] kids are scientists, the science equipment [is] expensive and their tools. [I] lay the foundation for a field of study or lifelong interest. (Post-observation interview, January 9, 2003)

Allison began the unit on insects with a classroom display of "Words that Scientists Use."

Figure 30.
Title: Words Scientists Use in Allison's Second Grade Classroom.



These were important strategies for having learners begin to think about what it is that makes "doing science" scientific. Students in all classrooms were eager and excited about doing science. Students' attitudes and behaviors also exhibited an awareness of safety and respect for others, equipment, and living things.

Tasks and Activities

Students handled simple scientific tools, materials, and/or organisms. The activities students engaged in were meaningful for learners to do, such as investigating the properties of water and electricity, the motion of objects, living organisms, and mechanical systems. Important to building a culture for science exploration was that the children were not necessarily engaged in identical tasks or required to do tasks in exactly the same way. Where it was feasible, this was observed to varying degrees in the five settings. For example, when establishing viable habitats for insects, it was important that learners worked together and followed the teacher's instructions. However, when asking questions or drawing their observations, students were free to select what was of interest to them.

Students in every classroom were engaged in common activities and purposes. The small group interactions were moments when students exhibited deviation from specifically prescribed behaviors and dialogue. However, students were bound to the overarching common questions posed by the teacher and the unit.

Time

As stated by teachers in this study, inquiry takes time. The fullness of the elementary school curriculum creates tension between teachers' responsibilities for coverage of the science curriculum and their responsibility to respond to learner's needs; questions and interests. Teachers were conflicted by their efforts to honor students' questions and making time for children's investigations in an already overcrowded curriculum. Teachers strove to complete the units during the time the kits were scheduled to be in their classrooms.

Time was organized based on school-wide decisions and on classroom instruction. A number of school-related interruptions were observed during instructional time. Lessons were altered or interrupted by fire drills, announcements, classroom visitors, school inspections, and students entering or leaving the classroom, as well as changes to the school schedule to accommodate school-wide events. Teachers also made adjustments during teaching for behavior management interruptions associated with classroom interactions.

The ability to use and manage time was different for each teacher in the study. Rachel and Natalie had the greatest control and flexibility over their teaching schedules. They were able to build in more time for science or move and integrate other academic content as they deemed appropriate. Allison and Tanya were fixed into a school-wide six-day rotating schedule, and Tanya was bound to a fixed time block for science that could not be extended or altered. Onna planned science time with her time-share colleague.

Teachers considered the integration of curriculum to be a possible adjustment to instructional time and to enriching the learning opportunities for students. When teachers actively sought to integrate their instruction, they did so by including writing, reading, computer technology, and mathematics.

ACC4: All of the teachers in this study could be placed along the Inquiry Continuum (IC) as engaging in "full" or "partial" inquiry. In planning and executing their lessons, teachers demonstrated the inclusion of at least four of the five essential features for classroom inquiry. In so doing, they satisfy the criteria for exhibiting "full" or "partial" inquiry, while teaching their respective science units.

> Sometimes inquiries are labeled as either "full" or "partial." These labels refer to the proportion of a sequence of learning experiences that is inquiry-based. For example, when a teacher or textbook does not engage students with a question but begins by assigning an experiment, an essential feature of inquiry is missing and the inquiry is partial. . . . If all five of the essential features of classroom inquiry are present, the inquiry is said to be full. (National Research Council, 2000)

The research findings were used to place teachers along the IC. The "Essential Features of Classroom Inquiry and Their Variations" published in *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (2000), was used to describe the inquiry variations represented by the Inquiry Continuum (IC). Case findings were used to identify the variations of inquiry in which students and teachers were involved throughout the unit overall. The assignment of a teacher to an IC inquiry feature is not absolute, but rather an indication of the degree to which teachers implemented their science instruction relative to achieving inquiry over the course of the study. The table adapted from *Inquiry and the National Science Education Standards* displays that all five classrooms in this study were engaged in inquiry teaching and learning. Teachers have been placed in the IC matrix according to the individual case findings described as assertions in Chapter 4 (See Figure 31).

Figure 31.

Title: The Essential Features of Classroom Inquiry.
(Adapted from National Research Council, 2000.)

Essential Feature	**Variations of Classroom Inquiry**			
1. Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions **Allison, Rachel**	Learner sharpens or clarifies question provided by teacher, materials, or other sources	Learner engages in question(s) provided by teacher, materials, or other source **Natalie, Onna, Tanya**
2. Learners give priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it **Rachel, Allison**	Learner directed to collect certain data **Natalie, Onna, Tanya**	Learner given data and asked to analyze	Learner given data and told how to analyze
3. Learner formulates explanations from evidence	Learner formulates explanation after summarizing evidence **Rachel**	Learner guided in process of formulating explanations from evidence **Natalie, Onna, Tanya, Allison**	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations **Allison**	Learner directed toward areas and sources of scientific knowledge **Natalie, Onna Rachel, Tanya**	Learner given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations **Allison, Rachel**	Learner coached in development of communication **Natalie, Onna, Tanya**	Learner provided broad guidelines to use and sharpen communication	Learner given steps and procedures for communication

OPEN INQUIRY←→GUIDED INQUIRY←→DIRECTED INQUIRY

This study sought to characterize how exemplary teachers manifested inquiry in teaching and learning in elementary schools. These descriptions are not intended to suggest more than a general interpretation of learners' activities while engaged in science lessons.

Based on post-observation interviews, the classroom teachers described their practice as being a form of guided inquiry. The interpretation of the data supports teachers' self-assessment of their practice.

If inquiry as a scientific enterprise is defined as a process of posing a question that can be investigated, designing the investigation, gathering data, and communicating an evidence-based explanation, then all of the teachers in this study relied upon a mix of approaches to teach inquiry-based elementary science that included[3]

1. Direct Instruction: "observational learning" (Eggen & Kauchak, 2001) or modeling on the part of the teacher as a means of guided teaching.
2. Lecture/Discussion: utilizes what learners already know (schemas), organizes conceptual constructs for learners, and uses questions to involve learners.
3. Cooperative Grouping and /or Group Work: a social interaction approach to supplement other instruction models, where learners work together to achieve a common goal (e.g., problem-solving pairs or teams).
4. Concept Attainment/Development/Formation: used when a lesson focuses on a distinct concept to be learned or reviewed; examples are introduced that lead students to the formation of the concept.

Descriptions based on definitions offered by Eggen and Kauchak (2001).

5. Problem Solving: a solution to an identified problem is considered, and strategies are developed to attempt a solution and evaluate the results.

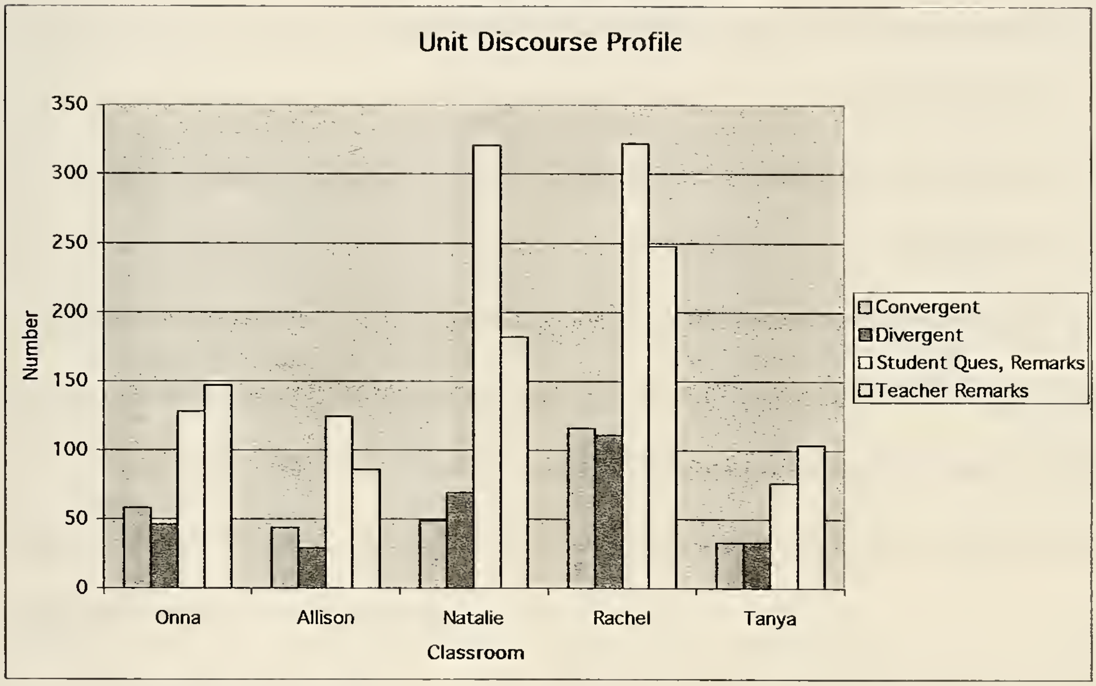
Inquiry is in the mind of the investigator. What manifests itself as inquiry in the context of teaching and learning are those behaviors that suggest a decision by the teacher to redirect the learner for the purposes of guiding learning. Teachers exercised their professional judgment about the nature of the learners in their classrooms in order to make instructional transitions as needed to promote positive learning experiences. For example, Rachel was aware of the potential for frustration behaviors on the part of learners from her prior teaching experiences with the Electric Circuits unit (STC). She exercised her judgment and accepted feedback from the learners about when they should stop and accept direction during their attempts with materials to build a switch.

The research finding illustrates how complex teaching is in general. Teachers do not necessarily pursue each teachable moment. They have to decide what they will pursue with the whole class versus individual learners and allocate their instructional time accordingly. In Natalie's classroom, a younger student was observed keeping track of how many responses were being recorded and the number of students present in class. The student voiced concern that there were 20 responses recorded and 21 students in class. This attention to record keeping, patterns in the data, and intellectual engagement on the part of the learner was not pursued by Natalie at the time the student brought it to everyone's attention. Natalie elected to acknowledge the observation and move forward with the intended investigation.

Questioning Profiles and Classroom Discourse

Regardless of the various instructional approaches employed by teachers, they relied upon the use of questions in their teaching. As the summary questioning profile illustrates, the type of questions asked or used by teachers was not necessarily a predictor of overall instructional style within this study.

Figure 32.
Title: Classroom Discourse Profiles.



Nor was the questioning profile an indicator for how much students offered their questions, responses, and remarks during whole classroom discourse. Teachers who asked more questions generated more student responses and discourse in general as illustrated by the cases of Rachel and Natalie. However, Natalie's profile is very distinctive relative to her peers. Overall, she was the only teacher who asked more divergent questions than convergent questions during whole class discussion. Another interesting distinction in the data is that the four teachers who are KS asked more

questions than the non-KS teacher. Teachers' remarks exceeded students' questions and remarks in two classrooms—Tanya's (non-KS teacher) and Onna's (ESL teacher). This quantitative data was thought to be representative of the differences in whole class discourse between classrooms and have to be interpreted with caution.

Natalie met the challenges in her multiage classroom for ensuring complete participation by having each learner contribute responses to her questions for data or about data. Natalie imposed an equity standard upon herself that ensured each child offer a statement or ask a question during the course of every lesson. Also, Natalie very purposefully recalled learners periodically during hands-on activities to check in with them about their investigative process and progress. This style of discourse generated more shared student dialogue for whole class consumption and multiple opportunities for different levels of process contributions suited to a multiage population. It is interesting to note that Natalie was the only teacher whose vocalizations were significantly less than learners' overall. This means that students spent more time during whole class discussion contributing than did their teacher.

Rachel also maintained an active awareness of which students she had spoken with or heard from in each lesson and made every effort to ensure that each learner made a contribution to whole class discourse. She accomplished this by selecting learners, using wait time to ensure the maximum numbers of hands were raised before calling on a student, and by allowing learners to select or call on each other.

The instructional styles of the other teachers were quite different as the classroom discourse data suggests. For example, Onna and Tanya conducted fewer whole class closings over the lessons observed. This means that lessons that involved learners with

materials did not always close with a review, summary, or sharing of findings. And in Onna's case, language development was an alternative agenda to her lessons, requiring her to model conversational English.

Tanya used a more lecture-based approach to her whole classroom discussions in general. It is not clear from the data how learners' need for reflection time contributed to the discourse profiles. For example, students are not always ready to discuss at the end of a lesson. The time that students need for hands-on science to be meaningful was not necessarily more time with the materials, but simply more time to think about what they had observed and done with the materials. Also each teacher had to decide when it was appropriate to use whole class questioning as a teaching strategy. Whole class discourse was used to monitor for attentiveness, selective or volunteer sharing of ideas or results, or to solicit students' questions.

The FOSS (c1993) units promote teachers to use recall questions, integrating questions, open-ended questions, and thematic questions in their science teaching.

Figure 33.
Title: Questions and Learner Thinking Processes.

Type of Question	Learner Thinking Process
Recall Questions	Learners remember information
Integrating Questions	Learners process information
Open-Ended Questions	Learners infer, create, and solve problems
Thematic Questions	Learners realize connections among scientific ideas and processes

The data presented in Chapter 4 of this study illustrates that teachers employed questions across the range promoted by the units.

Discourse in Groups (DIG)

What the study data helps to illustrate was the degree to which teachers controlled classroom discourse and the nature of the resulting discourse. What the data does not illustrate was the quantity and nature of student-controlled or initiated discourse.

Hands-on Time (HOT) was that time during each lesson when Discourse in Groups (DIG), learner-initiated or controlled discourse occurred between students. The nature of the student-to-student discourse depended upon the age, social dispositions, level of teacher monitoring, and the nature of activities in the individual classrooms. Learners were expected to have discussions about their work during HOT. Guidelines and rules existed, such as "accountable talk" (e.g., Rachel and Allison), which facilitated creating an environment for discourse development between and among learners.

Interestingly, during Onna's lessons, students were not given specific discourse guidelines. Discourse was encouraged that promoted the use of language and oral communication skills in general during Onna's lessons. Onna's first-grade students worked individually and often limited their student-initiated communications to display or share their success with materials. Students also provided directions to each other about what to do.

In Natalie's classroom, captains assumed responsibility for "accountable talk" within each of the student groups. Midway through the unit, one captain was able to transfer Natalie's persistent modeling of "What did you notice?" question used during whole class discussion to initiate DIG during HOT.

[In one group, the captain asks a Middler to explain what is happening. The Middler says the water is red only at the top and clear at the bottom. The other students offer the same results.] (Observation notes, October 17, 2002)

This sample evidence of student-initiated checking and confirming of investigative results within the context of HOT appears consistent with what Drayton and Falk (2002) describe as "student-to-student talk" in an "effective inquiry-based classroom." While such evidence was not captured in every observation or in every classroom setting, the intellectual work associated with "effective inquiry-based classrooms" was observed being done by teachers and students. Teachers presented materials and intervened in ways appropriate to model inquiry processes. Students learned from indirect and direct instruction from the teacher and each other.

In Rachel's classroom, students' DIG required learners to work on developing questions and processes for conducting investigations.

[I move around the room to see what students are writing for questions and doing with their materials. Two students have similar question in their notebooks: "Can you light two bulbs with three batteries?" Another student asks, "If you put two wires in a Fahnestock clip will it light?" Students working with partners are "sharing" questions—working to answer the same question, which means pooling materials.] (Observation, October 8, 2002)

The data suggests that the nature of DIG was connected to the nature of HOT experiences. For example, in Allison's classroom, introducing an insect served to generate questions, capture interest, and promote evidence of prior knowledge.

[Twenty children are present. The teacher walks around distributing insects. Children are very excited, talking loudly, giggling as they observe. They are guessing about what the insects are. Caterpillars are one popular suggestion. They touch it. Several are using the hand lens to look at the insects. Some verbal responses/exchanges are "yucky, yuck, yuck" mixed with "Ohhs" and "Ahhs."] (Observation, October 3, 2002)

Often DIG in Allison's room was discussing what was real, who had not had a turn, and what the insects were doing or going to do.

Tanya's students most often had such a limited amount of time during an observation to interact in their groups. The data for her class was limited to teacher initiated discourse. DIG was often limited to handling materials and building carts using trial and error as well as other problem-solving strategies, which was the focus of the curriculum.

ACC5: Teachers demonstrated an equitable approach to science instruction in their classrooms. In every classroom setting, there were students classified as needing special education resources or other supportive education services. In every classroom, teachers worked to ensure that all students were involved in science learning. Students scheduled for services or students that arrived late to class were recognized and accommodations.were made to include the children as thoroughly as possible. Students that received resources outside of the classroom were oriented to the lesson goals and objectives before they left the classroom, as in Rachel's classroom. When they returned, they were immediately brought into the activity at an entry point appropriate to where

they left. The reentering students selected where they would work and were included in the whole class review process.

In another setting, in Natalie's classroom, a student who arrived late to class was brought into the lesson by two peers selected by the teacher to provide a set induction for the learner. The peers successfully oriented the learner to the lesson, and the student successfully completed the lesson with his classmates.

These examples of attending to learners to include them show individual learners that they are important and that science is an important subject to be taken seriously. It conveys to learners that science is for everyone and everyone does or is expected to do science. Learners who receive services were acknowledged productive members of the classroom.

In one classroom, a student was repeating the grade level. This presented an interesting challenge in relation to the science curriculum. Since the LSC districts (where this learner had been placed previously) all use the same kits at the same grade levels, this learner had completed the unit a year earlier. The students' prior knowledge and experience were viewed as a positive resource from which all of the learners in the classroom could benefit.

Throughout the study, it was noted that classrooms had on average an even number of boys and girls. The girls appeared as likely as the boys to handle equipment and investigate events. In two classrooms, the researcher shared this observation with teachers. Allison, the second-grade teacher, indicated that the boys were more likely to be hesitant in class to pick up the insects. Tanya, who teaches fifth grade, believes that she is seeing a population of female students who have had some experience with hands-on

science since first grade, and the engagement in science on the part of the female students reflects their learned expectation that they can do science.

In the multiage classroom, issues of equity regarding age and role were informally monitored. Again, the data suggests that all students shared in the community responsibilities of doing science to the extent that their abilities allowed. Captains (Olders) made sure that every team member had an opportunity to handle materials, record data or participate in recording data, and Youngers frequently offered responses or provided responses to questions when called on by Natalie.

It seems reasonable to draw the conclusion that full inquiry also means that all the learners were active, productive participants in classroom lessons. This is considered to be an important interpretation of the data absent from the inquiry matrix in the above section.

ACC6: Science notebooks were used in similar and different ways across the sites as indicators of inquiry and science learning. In the four classrooms where students maintained notebooks, they did so in very different ways. This is an important finding that impacts the interpretation of students' communication of scientific ideas and process as a feature of inquiry.

Writing is a form of thinking, a way of displaying and communicating thinking. How students are expected to write in science, therefore, represents or conveys information about what is valued in scientific thinking by the teachers and the students.

Where science notebooks were maintained, teachers structured the notebooks. Students were expected in each of the four sites to keep either a Table of Contents and a page numbering or chronological sequencing system. If page numbers were not used,

then lesson number or topic sequenced the notebook entries. Teachers prepared notebooks in advance of the unit for students. Teachers of multiage and second-grade students provided them as bound notebooks with pages that were prepared forms. The forms had a place for diagrams and a place where students could put written responses. The fourth- and fifth-grade students used three-ring binders, which contained prepared sheets for student entries.

Students were asked to make entries in different ways across the settings. For example, students in Natalie's classroom entered what the teacher modeled to ensure that emergent writers and readers were learning how to read and write as well as how to maintain an organized notebook. In Rachel's classroom, students were asked to make an entry of their thoughts and questions in a more open manner. On the left hand side of the notebook page, students were encouraged to write their questions and ideas in any way they wanted, at any time they wanted. While in Tanya's classroom, the whole class was led through a process of possible entries and where to make those entries within the notebook structure. Students in grades four and five maintained a Glossary, while students in other grade levels did not. Students in Allison's classroom also were free to enter whatever they thought or found important to write in the notebook sections. Supplemental handouts, worksheets, or assessments were also kept in science notebooks across the sites.

What made this information useful to this study was the degree to which the notebooks served to answer the following questions: How much do the notebooks represent students' engagement with the content and processes of science versus

recording teachers' interests? Did the notebooks support children's inquiry in elementary science classrooms?

In those instances where learners were encouraged to record their questions and to write or draw what they found important or interesting, students were empowered to utilize notebooks in a manner consistent with communicating students' ideas to teachers. For example, Rachel assessed the nature of the questions students had recorded in their notebooks during the unit, and she recognized that students needed a chance to explore those ideas. As a result, Rachel altered the unit plan and introduced her Mish-Mash Review Lesson. This was an instance where notebooks were used to plan and make instructional decisions using learners' questions. Rachel's approach was illustrative of the learning or inquiry cycle in science learning. Students asked questions about electric circuits and designed and conducted investigations in an attempt to obtain answers to their questions. They created ideas about what they observed and did and discussed their ideas and reflected during whole class discussion and in their science notebooks about the results and the possible meanings of those results. Rachel allowed learners to pursue very different questions, and she did not alter or change students' questions. She let the questions stand and elected to support and guide the investigative process and the subsequent discussions.

Another commonality was that the notebooks were used to formally assess learners. In three of the settings—the multiage, fourth-grade, and fifth-grade classrooms—teachers made comments, left questions, or offered suggestions in relation to student entries. These teacher entries extended the dialogue with learners about science to greater and lesser degrees. Where teachers offered critical feedback about what

learners wrote, or created additional performance opportunities, teachers were furthering science thinking. Where teachers made "acknowledging" comments, students' thinking was affirmed. Utilizing notebooks in these ways also promoted equitable practices in science teaching. The notebooks reflected or validated the unique communication styles of learners. The notebooks directed and extended dialogue beyond science time when whole classroom time or DIG did not permit these important conversations to take place.

One reason for notebooks in science is to have a record to refer to in the future. Scientists document what they do so they can repeat or make changes to their investigations and/or questions. Notebooks are reflective tools for the researcher. As part of the "like-a-scientist" effort prevalent in current science education practices, it is important that classroom notebooks serve a similar purpose. Students should be able to go to their notebooks for information, to review their processes, thinking, materials, etc.

In this study, it was observed that some students voluntarily referred to their notebook entries, Glossaries, and Table of Contents to locate previously entered information. Most importantly, students were observed voluntarily reading their notebooks. Students were observed reviewing previous entries and reading their responses to questions, drawings, questions they asked, and teacher comments. Allison, Tanya, and Rachel incorporated "reading in the science notebook" as a planned lesson activity. The notebooks served as a way for learners to self-review and reflect on their science learning and activities to date.

Chapter Summary

This chapter discussed those research findings that address the research questions, described commonalities between settings, and identified significant differences between the settings. The findings indicate several shared similarities among teachers.

1. They provided an average of approximately 34% of class time for hands-on investigation and used kit-based curricula to teach elementary school science.
2. They value inquiry as an instructional and learning process that involves asking questions, using materials and hands-on investigations, offering explanations, and using evidence. Students in each setting experienced these indicators of inquiry differently.
3. Their instructional efforts were directed at employing and realizing their understanding of classroom inquiry. Teachers in this study continued to evolve their understanding and practice of inquiry as a process for science and instruction.
4. They were implementing inquiry to various degrees consistent with accepted notions of classroom inquiry, and all of the teachers can be described as essentially having guided inquiry practices. All of the teachers in this study self-assessed their practice as being a form of guided-inquiry.
5. They varied their instructional approaches in order to achieve their instructional goals, to respond to learners' needs or interests, to adapt the curriculum to make it more inquiry-oriented, and to accommodate externally imposed conditions. In every setting, teachers faced challenges and barriers to their planned unit design.

6. They employed an equitable approach in their teaching of science to include diverse learning styles and needs.
7. They all used questioning strategies to direct or guide students' inquiries and related thinking during whole class discussions.

Areas of notable differences, either by degree or omission were:

8. Three of the five teachers did not directly utilize students' questions as a basis for planning inquiry experiences with learners.
9. Four of the five teachers had students maintain science notebooks or journals, however, there was a range in how the notebooks were used to promote and extend science inquiry and learning.
10. Teachers relied on many different knowledge sets when teaching.
11. Despite having similar definitions of inquiry that were also consistent with accepted definitions of inquiry, each teacher did not actualize inquiry as completely or fully as desired due to factors in the environmental setting of schools.

It may not be possible for all of the elements of inquiry to be present for inquiry to occur in light of the dynamics of classrooms and schools. This researcher believes that the elements that can contribute to inquiry science learning have been successfully identified for inclusion along the IC. Teachers who have a highly developed understanding of inquiry may be more likely to recognize and make informed decisions about how to implement inquiry teaching, but as this study shows, exemplary teachers are still evolving in their thinking about how to teach elementary school science using inquiry.

Chapter 6

Conclusions and Implications

This study investigated the nature of inquiry-oriented instruction in elementary school classroom science as manifested by five exemplary teachers. The teachers were situated in an LSC and have been supported in their efforts to employ hands-on, inquiry-based science curricula in public schools.

The assumptions on the part of the researcher was that teachers in the LSC districts were using NSF-endorsed inquiry-based curricula to teach science, and that the teachers identified by the LSC project personnel as exemplary would demonstrate the use of inquiry practices over the course of the field study. It is a conclusion of this study that these assumptions have been affirmed.

This chapter provides a summative discussion of the findings in relation to each research question. Following the discussion of the research questions are the conclusions and potential implications of the study.

I. Research Questions

This study sought to document elementary teachers situated in a first-round LSC adoption of inquiry in their classroom practice. The study used classroom discourse and observations of learners' activities to connect inquiry practice with the Inquiry Continuum (National Research Council, 2000).

1. How are teachers implementing inquiry in their teaching of science? Five exemplary teachers within a first-round LSC exhibited the five essential features of

classroom inquiry in their teaching as defined by the *Inquiry in the National Education Standards* (2000) to varying degrees. Teachers were providing learners with scientifically oriented questions using kit-based curricula adopted by the LSC collaborative school districts. Their inquiry instruction was found to be mixed or blended with other instructional approaches appropriate to their needs within the setting, content goals, and student audiences. Teachers utilized questioning strategies that structured convergent and divergent questions consistent with theoretical tenets of building inquiry processes with learners through dialogue. Teachers' questions focused learners on science factual knowledge, conducting empirical investigations, use of simple science materials, developing explanations from evidence, and communicating scientific ideas. The questions that teachers asked reflected the nature of the investigative goals of a given lesson. Unit investigations varied from being descriptive and classificatory to being explanatory in nature.

The teachers relied upon the unit questions for developing their lessons and did not rely upon learners' questions to a significant degree for planning investigations. However, two teachers did invite and plan for learners to ask and answer their own questions either through empirical investigation or the use of other resources such as the Internet and books.

Teachers employed questioning strategies that supported science learning and inquiry. Questions allowed teachers to assess or activate learners' prior knowledge, guide learners' explorations and their explanations, or to extend students' thinking. The degree to which teachers engaged learners in each of these important features of inquiry was

dependent in part upon the grade level of the learners and the comfort teachers had with negotiating challenges to inquiry inherent in the setting.

From the analysis of the data, it can be concluded that teachers in this study actively engaged in inquiry-oriented instructional strategies; that is, their teaching resulted in learners engaging in inquiry processes.

2. How do teachers view the use of inquiry as an instructional model for teaching K–six science? The teachers in this study portray the use of inquiry as an important instructional approach for teaching elementary school science. Teachers' perceptions of inquiry indicate that they view the processes of inquiry to be consistent with scientific ways of asking and investigating questions about the natural world. Teachers in this study invested a significant number of hours of PD targeted at improving their use and understanding of the kit-based curricula and science content. They have been active in promoting inquiry-based science teaching in their roles as science education teacher leaders. The criterion used by the LSC staff for selecting these teachers was that they exemplified characteristics of teachers who seek professional growth and improvement in science education rather than the actual practices of the teachers in classrooms. This study provided an opportunity for the researcher to document how these teachers integrated their acquired knowledge and skills to teach science to elementary school children.

Teachers' self-assessment of their inquiry-based teaching proved to be essentially accurate based on the analysis of the data in this study. In some respects, however, the teachers did not achieve the level they had anticipated or hoped. For example, students' questions, while they were cited as being important, were not used to plan investigations

in three of five classrooms. This suggests that teachers are not able to optimize a full inquiry approach in their classrooms.

Teachers' notions of classroom inquiry were articulated in a manner consistent with the nature of elementary school-age learners. That is, teachers recognized that what scientists do represents expert practices and outcomes. Students' inquiry experiences need to be designed for learning about inquiry as well as learning how to do inquiry. Teachers recognized learners' needs to have experiences from which to create and build new knowledge. They actively make decisions to inform and provide factual knowledge and to guide learners' activities and thinking.

3. What is the alignment of teachers' implementation of inquiry in the classroom with accepted definitions of inquiry? Teachers' practices observed in this study were aligned with the five essential features of classroom inquiry and other accepted definitions of scientific inquiry for elementary schools. Actions and behaviors absent from classroom settings in three of the five classrooms were: students formulating their own questions, and students designing their own investigations. In one classroom in particular, students did not actively critique the scientific process, record data, or engage in alternative modes of investigation and problem solving beyond relying upon their empirical observations.

In all settings, prior lesson events did impact the design, delivery, and activities of subsequent lessons, and teachers made efforts to connect classroom science with real world events or other areas of the curriculum.

Students were actively guided throughout the units with scientifically oriented questions that were interesting and meaningful to learners, albeit these questions were not

necessarily those of the learners. Teachers asked questions that directed learners to compare results or posed problems and alternatives for learners to consider.

There was a range in how teachers conducted their lessons not just across sites but within a given classroom as well. Teachers varied their instructional approaches from explorations to very directed lectures.

Students' attitudes were positive during science in every setting. The level of student excitement in one classroom often required the teacher to use management techniques to ensure learners' attention before beginning or continuing with the science lesson. Students maintained an interest in the science being taught, and they exhibited enthusiasm for doing more science once the units ended.

II. Other Conclusions and Implications

The findings from the cross-case analysis of the data potentially serve to illuminate several important instructional considerations for teachers seeking to evolve an inquiry-based, constructivist-oriented approach to teaching science to children.

Instructional Time and Use

Appleton (1997) describes two levels of students' responses during science lessons: deep processing, or cognitive restructuring, and surface processing (see Figure 34).

Figure 34.

Title: Appleton's Figure for Processing.

Deep Processing by:	**Surface Processing by:**
Comparing information to a tentative idea	Focusing on concrete aspects of event or encounter
Using analogies	Accepting the vague ideas as an adequate answer, which will be reexamined only if the context requires this to happen.
Making thought experiments	Accepting the vague idea, but trying to confirm it and/or perhaps clarify aspects

Data from this study suggest the teacher-guided "discourse in classrooms has a central role in scientific activity" (Shimizu, 1997). Inquiry happens through discussion about concrete or hands-on events and ideas as a process of interpretation and making meaning of events observed and documented.

Where constructivism has been articulated as an instructional philosophy for science inquiry (Chapter 2), teachers are required to acknowledge learners' theories and beliefs and accept them as a central basis from which to plan investigations and discussion; that is, teachers begin teaching from where the learner is. However, the curriculum is an important actor in the communicative design of science teaching. Curriculum presents teachers with the challenge of interpreting science and communicating that interpretation to learners. Constructivism as a window onto science teaching requires that the analysis of science teaching begin where the learner *and* the teacher are.

In the 1960s NSF-funded developers of elementary science materials sought to introduce curricula that would provide an adequate staging for the adoption of full

inquiry in schools. The data from this study suggests that there exists potential for teachers to evolve beyond that initial staging in the present science education reformation phase. This is an important finding for LSC initiatives and similar projects. The professional development that these exemplary teachers had resulted in the desired impact on their practices. That is, these teachers have been immersed in growing a deeper understanding of what inquiry is and how to use inquiry to teach science. This was an underlying assumption in the criteria established by the project for identifying exemplary teachers for the study.

A substantial amount of time was given to learners' doing the stuff of science—using their five senses and extending their five senses as they examined the natural world. Teachers in this study dedicated as much as 39% of class time on average—as in Onna's case—to this important and necessary process of sciencing. However, hands-on time is not a guarantee for inquiry. Hands-on science may be necessary, but it is not sufficient for inquiry in science. The other essential component is meaningful discussion about the hands-on experience (Saul & Reardon, 1996).

Inquiry discourse means extending actions and thought, creating new theories, confronting existing theories, applying new knowledge, testing new theories, challenging the processes used during inquiry, and moving on toward refined or new inquiries, or "using, in short, all available resources" (Engel, 1996). For teachers in this study, all available resources were used in their pedagogical toolboxes. Teachers made modifications and adjustments to the setting, the learners, the content, the kit lessons, the kit materials, the physical space, and employed multiple assessments. Every teacher had something that they were trying for the first time as well as the umpteenth time in their

teaching of the kits. This sorting through the pedagogical tool box and emerging with inquiry was, at times, impromptu, such as Natalie's decision to give the children in her class "free exploration time" with water. At other times, teachers were very deliberate about their adaptations, such as Tanya's dedicated efforts at also letting children build and design wind-power carts as a culminating and extending project to close the Models & Design unit, or Rachel's plan for her "mish-mash" exploration lesson.

Inquiry is as much a journey as it is a process. Teachers in this study suggested that it was important for elementary learners to experience guided practice with inquiry processes in order to become independent inquirers. This was conveyed when they articulated to the researcher that children need a structure for initiating explorations. This created a practical and conceptual tension for teachers. Teachers needed to teach about inquiry in order to facilitate students' abilities to engage in science inquiry. Teachers expressed this tension in their concern about using students' questions and allowing more time for open exploration, which are two traditional tensions to teaching and learning in elementary school science.

Science evolves through both fluid and static inquiry developments (Chapter 2). Classroom inquiry required teachers to give attention to the technical aspects of science, such as proper equipment use and technique. Classroom inquiry focuses on building such foundational experiences to support the growth of static and fluid inquiry. The kit-based curricula supported guided inquiry and were used to convey and examine accepted (e.g., static) science knowledge, while affording learners the enjoyment of the intellectual freedom associated with the fluid discovery of knowledge new to them, or revisiting prior understandings from an alternative context. Data from this study illustrated this over

several instances appropriate to early childhood development (grades one through three). An illustrative example from Natalie's classroom is provided.

> [Teacher draws and writes on the newsprint paper: Water on a Slope.]
>
> Teacher: We're going to have a water dome race [with one through six drops]. [Teacher demonstrates as she speaks.] Ready, set, and very gently [raises the tray]. Don't go fast and see who gets to the bottom. [We'll] see if all [the drops] get to the bottom. What are you going to predict based on what you just discovered?
>
> Student 1: The big one will win.
>
> Student 2: The little one will not go down.
>
> Student 3: The second drop will not make it.
>
> [Teacher continues taking predictions from children.] (Observation, October 3, 2002)

Natalie asked learners to recall experiences from earlier in the lesson and apply the knowledge to the new situation. Natalie had learners focus on the depth of science processes. Students were manipulating and observing real objects and events, considering questions, making predictions grounded in prior experiences, and considering the predictions of others. The students did not simply conduct the investigation and look to see if their predictions were right or wrong. Natalie moved learners to a more metacognitive process of sciencing by asking learners to reconceptualize the events and record the investigative set up and findings. They were asked to predict—a thought experiment process. They were asked to rely upon previously obtained data to make that prediction—the interpretation of evidence. Then Natalie asked her multiage learners to

reflect upon their investigations in whole class discourse and as individuals through their journal entries.

> Teacher: What would a good title be? [Water on a Slope] . . . Draw what will help you remember. Now you have two questions, describe what you observed when water was on a slope. (Observation, October 3, 2002)

The students were directed to engage in an important habit of mind in science culture. The classroom teacher could have viewed the science as "done" when students completed the hands-on activity and presented their findings. But in the illustrative example from Natalie's case study, students were asked to reconceptualize their actions and the events and revisit them multiple times through: (1) their observed repetition of the investigation in their groups; (2) their discourse of the findings and events, in group and as a class; and (3) their individual documentation in their science journals. Natalie's practice is "good classroom inquiry" as an early childhood expert. Early childhood learners need multiple experiences and opportunities for multiple expressions of those experiences as part of the larger conceptual process of working toward explanation. Natalie continually moved the learners further toward the habits of mind in science consistent with the developmental ranges and abilities in her classroom.

> [Teacher moves around the room, asking students, "Can you show me slope?" in their drawings. Some of the Youngers need help writing. Teacher moves to them and asks questions, offering encouragement, and after she leaves these students, they begin to write in their journals.]

Teacher: Oh, I like the way you did this. One thing I would add are [the drops.] [Teacher illustrates and verbally counts out the drops 1, 2, 3, 4, 5, 6.] I don't know how you would do this.

[The student takes the journal entry and makes changes.] (Observation, October 3, 2002)

The "hidden explanation" for the Younger was to identify what aspect of the set up led to the observed behavior of the water beads—the slope. It was a critical feature to the set up and worthy of descriptive documentation by learners when they revisit their findings: All the water beads retained their dome shape throughout the slope race, and the biggest bead won the race. It can be argued that this was also a science word vocabulary check, and it was. However, the names of things are important in any culture and science is a culture embedded within a social culture, and the language of both cultures was being learned. Finally, as members of a community engaged in the study of science, creating a common language (whether traditional to formal science or not) was another important learning goal for Natalie consistent with the habits of mind in science.

Taking Time to Think About Inquiry

It takes time to think, and more time to act on thinking. This study illuminates the challenges and successes to reforming science education in elementary schools. The kit-based curricula provided teachers with valid science content presented at an age-appropriate level (depending upon district-level decisions for sequencing the units) that have an established history of field use, evaluation, and research. However, the exemplary teachers in this study found that the kits imposed restrictions to inquiry owing to the prescriptive nature of the units. Teachers in this study began to address these

perceived restrictions through their modifications to the intended units and their instructional approaches. One teacher in this study described her early uses of the curriculum as "mechanical." During her initial teaching of the unit, the teacher had to learn the how and why of the unit design before feeling comfortable enough to make meaningful changes in the use of the materials. The teacher also had to monitor students' responses to teaching the concepts with the materials. For this teacher, the time spent with the "mechanical use and exploration" of the curriculum was two to three years—about 36% of her total time teaching with the materials to date. Inquiry into science content and processes takes time.

The teachers in this study were defined as exemplary because of their determination to change and improve their science teaching based in part on their commitment to PD. Through this study, it was possible to glimpse their practices for evidence of how they have incorporated their PD experiences into their teaching. These highly motivated individuals provided some sense of the type of inner resources reformers ask teachers to muster on a continual and daily basis over years of professional practice to achieve open or "full" inquiry in their classrooms. Teachers require time and continual support to identify and utilize relevant PD opportunities. It becomes an interesting implication of this study for the providers of science education PD to explore what PD is appropriate and useful to teachers in LSC projects. In the early years of these systemic change projects, the PD agenda was kit training, training in and orientation to science inquiry, and science content. What combination of PD experiences should teachers have several years into the reformation process?

Teachers in this study have begun to reflect upon how they utilized students' science notebooks in relation to the broader mandatory testing agenda in writing and reading. Two of the teachers attended a summer institute about integrating writing in science. The researcher attended that PD institute in order to have an understanding of what students would be asked to record during the study. The teachers from this study who attended the institute integrated what they learned into the science units they taught during this study. Given the importance of local agendas to promote literacy and improve reading and writing test scores, it is not unreasonable to include more writing in science. However, teachers need to explore in what ways learners' active use of notebooks support the goals of an inquiry-based science curriculum.

Teachers' and Students' Questions

Students were not always able to articulate their initial responses to events and required time to reflect on their observations. In these instances, classroom discussion focused on narrower aspects of inquiry, such as documenting the observations and the process of observation. Convergent questions guided students toward this important process of beginning to think about what happened and identify critical events and information. Sometimes "naming" or giving names to events assisted learners' in forming questions. As Sheila Jelly states in her essay "Helping Children Raise Questions and Answering Them" (Jelly, 1985/2001 in Harlen, (Ed.)), teachers must learn to distinguish between "productive and unproductive" questions. This applies to the questions teachers ask and the questions that children ask. Productive teacher questions are those questions that promote inquiry and exploration, are grounded in actual events, and do not promote "science as information."

Divergent questions promote explanation, analysis, and application to answer the how and why it happened questions. Teachers in this study used questions to promote or facilitate deep processing.

Allison's data represents the subtle use of divergent questions. For example, in Lesson 2, students were examining and reporting their observations of larva. As Allison fielded the students' observations, she paused to ask an important question designed to have a learner think deeply about the complex science process of observation. The student had shared changes to her insects with Allison. Upon consideration of the students' remarks, Allison recognized growth in the learner's capacity to observe. She also recognized a moment for deeper self-assessment by the learner.

Teacher: Did the larva change or [did] what you noticed change?

Student: What I noticed changed. (Observation, October 10, 2002)

The second-grade student was able to respond in a way that suggests she understood something about her perspective as an observer. She was made aware of changes in the way she was observing, as a result of Allison's question. As a researcher looking for evidence of children changing how they think over time, this was an important exchange. Allison's divergent question went to the heart of what it means for a scientist to observe. In science, observation is not simply what is "seen," but how events are seen. The researcher considered this to be a fairly sophisticated exchange about science process in an early childhood classroom. It illuminated the connection between "real" science and "school" science in the context of instruction. Observation as a deep science process was equally complex for the novice second-grade scientist as for the expert scientist.

Teachers in this study used a range of questions to review factual information, check learners' reasoning, stimulate thinking, and evaluate or assess learners' understanding. When teachers felt it important and necessary to do so, they modeled questioning or provided information to learners to move them to think of questions. Teachers attempted to build meaningful connections between the hands-on experiences of learners and relevant science concepts.

> Onna: What do we know from balancing the crayfish, the arch, and the triangle? Where were the clothespins? Were they up high or way down low? (Observation October 8, 2002)

Onna's ESL first graders relied upon active demonstration to show what they understood and how they understood balance and motion from their hands-on activities. This was a transition in their thinking from the way in which several students indicated what they knew about balance at the start of the unit. Some learners lacked sufficient command of English to even articulate what they knew at the start of the unit. By the midpoint of the unit, they understood balance point and that counterweight placement was necessary to balance an object. This explicit factual knowledge was gained from messing about with objects provided by the kit. Onna asked the questions that required learners to connect what was common to the objects' balanced states. Her questions and repeated use, demonstration, and modeling of vocabulary helped to create meaning that could be spoken and shared.

Students' questions were not always used directly by the teachers in this study as already stated. This has been presented as a possible area for growth on the part of teachers, but it is also acceptable to classroom inquiry for early childhood teachers not to

use all of learners' questions for several reasons. First, as Jelly (1985/2001, in Harlen) has indicated, learners ask questions for a variety of reasons. Some of the questions are not related to science or the questions have no answers. Forming productive questions is not easy. Learners have to have a conceptual framework and a language base from which to proceed. If the material is new to learners, they will require time to reflect on the new experiences. While the goal is for teachers to use more of learners' questions, it is important for teachers and others to recognize the various ways in which that can and does happen. Students may not be ready to formulate questions. They may need to repeat their experiences to relive or reinvent their original assumptions and expectations.

Onna and Tanya did not always feel compelled to conduct formal summarizing closures to their lessons. Students were allowed to continue their work until time ran out, and learners continued their investigations at the next scheduled lesson. This was consistent with earlier observations of classrooms where teachers employed hands-on learning using the Elementary Science Study (ESS) units:

> Following a rich session of experimentation, they [the teachers] find children are not necessarily ready to summarize or share experiences. Summary and generalization may be appropriate at some times, unnecessary and perhaps misguiding at others. The problem of helping teachers to discover a creative rhythm between experimenting, discussion, and summary is one on which we have worked most. There is no formula, and presenting "rote" practices of discovery is a hazard we have tried to avoid. We have tried to encourage teachers to work at achieving a balance in their own way. (Elementary science study newsletter, February 1965)

Teachers have to make these determinations based on their knowledge and assessments of the learners.

Research has shown that teachers hesitate to use students' questions for a number of reasons (Ediger, 2001). In this study, one teacher indicated that using students' questions posed a problem when students' questions did not necessarily match the curriculum goals. It is this researcher's belief that students' questions always match the goals of inquiry-oriented science instruction. That a student raises a question is indicative of some "compelling situation" (Gunstone and Mitchell, 1998) in the setting for that learner. The learner was stimulated to offer a question, even if on the surface it appeared to be unrelated and nonproductive to adult goals and purposes. Every question, therefore, requires a response and has value, if not to curricular goals, then to the goals of an assessment system designed to gain understanding of the learner. Knowledge of the learner is essential in measuring the real purposes of a given learners' question and how best to answer it. Even so-called silly questions have value, if not to the immediate content, then certainly to understanding the learner. Teachers must invent ways in which students' questions are honored, as there is no way to predict where a question pursued will lead.

Rachel, Natalie, Tanya, and Allison made notebooks repositories for children's questions. Onna was faced with responding to questions in the moment or not at all, given that no such storage system was used during her science unit.

Teachers are required to implement approaches that also honor children's interests and the processes of inquiry. Allison let her students explore their science-related questions using alternative resources and was able to integrate the use of technology in

the process. This proved a management challenge to her, because her classroom did not have Internet access. Therefore, Allison had to extend her science planning and preparation to the school librarian and reconfigured her class and schedule to ensure learners the opportunity to ask and pursue their questions. It seems reasonable that over time Allison has learned how to respond to the unpredictable aspects of working with nature (e.g., living organisms). Once the unit began and children's interests were ignited, there was no turning back even if every organism in the classroom expired. There was discussion about what could have caused the fatalities of the milkweed bugs, and students began the process of scientific investigation in any event. And, if every organism had flourished, then that would have created another set of questions.

The ESS quote above is striking in the sense of the timelessness of the issue it raises in relation to the role curriculum plays in how science is experienced. While teachers discussed the restrictions of the units they taught, there were two levels of response to their concerns. The first, as indicated by the ESS Newsletter, was that discovery cannot be prescribed by the developers of curricula. The kits as units offer models that teachers can use to initiate a process of viewing the natural world. Given that units are models, they lack the completeness of context learners need to assist them in formulating questions and ideas.

The second level of response was to use the inherent "flaws" or limits of the science units. Rachel shared her concern during an exchange about the limits of inquiry when she teaches the Ecosystems (STC) kit (post-observation interview). She related that the unit imposed many restrictions to learner inquiry, because once the eco-columns have been constructed and set up, students cannot really see the other organisms, except for the

crickets, and they die first. Her students can see the fish and the elodea, but no one really can tell what is going on with the snails or the soil-colored isopods. The model has limits to what things learners can and can't observe, but that does not limit what they can investigate. Allison's Insects unit suffered from the same restrictions as the Ecosystems unit. Teachers have to make decisions about what they can and cannot do with the kit materials and how they will move their discourse to address the limits of the scientific process inherent in every science-related effort.

Concluding Remarks from Multiple Perspectives

The Researcher

There are numerous studies in the literature that seek to discuss and describe the effectiveness of inquiry in science education[4]. Researchers have used a variety of indicators of inquiry as a basis for determining if teachers are employing inquiry practices and if learners are experiencing science inquiry. This study used the essential features of classroom science inquiry as presented in the companion publication to the *National Science Education Standards*. The Inquiry Continuum served as a reasonable tool for describing elementary teachers' science teaching. The IC model reflected the observed range of the actual classroom practices of teachers of grades one through five.

The data from this study supports that inquiry can be attained to varying degrees by teachers who have received extensive PD in science and science inquiry consistent with constructivist views. The degree to which inquiry is manifested by teachers'

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[4] An Internet-based ERIC search of keywords "science and inquiry" yielded over 3,800 abstracts.

instruction depends on a number of variables in the setting as well as teachers' understanding of science and inquiry.

Teachers in this study effectively taught science using kit-based units. Student artifacts and performances offered supporting evidence that the students had meaningful experiences with science concepts and processes. The teachers were not able in all cases to complete the intended curriculum, but learners demonstrated understanding and skills consistent with the curriculum objectives and goals that were taught.

For teachers to continue to develop their inquiry-oriented pedagogy and extend their effective use of the kits, they require continual support and assistance in identifying or developing appropriate PD plans.

Teaching With Kits

The kit units perform an important function. They provide teachers with materials, some background content information, and resource lists for implementing the unit. Traditionally, teachers have had to plan what to teach. Kits allow teachers to plan "how" to teach science. Yet teachers are still concerned with "what" to teach. A surprising finding from this study was the degree to which teachers with years of kit-based experience still followed the kit lessons. Or perhaps it was surprising how little they deviated from the lessons.

If there is a weakness in the design of the kit materials it is the failure of the developers to emphasize the wonder and excitement of science. At times, the teachers in this study did not go with moments of curious wonderment that resulted from puzzling or discrepant events. In two classrooms, there were unexpected events that teachers were at a loss to explain in the moment of instruction. Rachel and her students could not get the

brass fasteners on circuit boxes to conduct electricity as a result of the amount of oxidation of the fasteners, and Natalie measured the temperature of a cup of liquid water and found it to be 29 Fahrenheit. Natalie could not offer an explanation as to why the cup of water was not a solid given that the temperature on the thermometer was below the established freezing point of water. This became a tense moment given that she had just discussed with learners that water freezes at 32 Fahrenheit. In both instances, the teachers first communicated their surprise and confusion, and then deferred to the researcher as an on-site science expert for clarification. That they sought an external science authority when faced with these apparent contradictions brought home two important features about teaching with inquiry-oriented curricula:

1. The kits exposed students and teachers to real events and, therefore, the real issues of doing science.
2. The exemplary teachers did not take advantage of the investigative nature of science when faced with the events that appeared to deviate from the general principles and laws being studied.

The teachers did not seek to add investigative value to their teaching. In ideal "good classroom inquiry" the teachers would embrace these discrepancies as teachable moments for themselves and their learners.

Good Classroom Inquiry

Five variations of "good classroom inquiry" in elementary science were observed during this study. Good classroom inquiry manifests itself when teachers and students are engaged in explorations that further their understanding of natural events. The explorations that comprised the units in this study were descriptive, investigative, and

explanatory. Teachers engaged learners in experiences that stimulated the interests of children and were consistent with what science values as useful knowledge. Good inquiry in the five classrooms focused on the learners' and their experiences in the natural world or with real world phenomena. Teachers were responsive to student comments, questions, and statements, and teachers sought to make science come alive for their learners.

While it remains a point of growth for teachers to create space for children to ask and answer their questions through an investigative process, this is an ongoing struggle across the curriculum that is not unique to science. Teachers in this study were just beginning to examine ways in which to integrate science across the curriculum (e.g., through writing and language arts). The teachers were caring and artful in their ability to make science inclusive and accessible, while adhering to their current understandings and beliefs about inquiry. They actively reflected on their science teaching during the study.

The dynamics of whole class discussion and small group discourse is an area for further research in defining "good classroom inquiry." The teachers in this study used whole class discussion to bring together the similarities and differences of small group and individual activities. The selective process of "calling on learners" in the whole group setting was not for the purposes of assessment per se. Formal assessments fell to explicit active performances with materials and/or science notebook entries. What function did whole class discussions serve in the documented cases of "good classroom inquiry?"

Whole class discussion was an instructional strategy for teachers in this study. Through the judicial and selective "calling on" students, teachers enabled individual learners to model or practice important skills, different ways of thinking, and the use of

language, or to mediate and diffuse frustration. Experienced teachers know that calling on a few learners assesses only those few, and so to use valuable class time in such a way must serve a larger instructional purpose beyond that of assessment. In this study, teachers strove for deep processing by encouraging reflection, listening to others, and expressing what happened and what didn't happen, and, at times, how and why it happened. Whole class discourse allowed teachers in this study to bring forth evidence, identify ideas requiring clarification, review, or to provide necessary information.

In science, knowledge results from collective and collaborative processes. This means that internalized realities have to be externalized to become useful beyond the individual. When scientists report out their findings it is to obtain feedback from peers, to seek confirmation, validation, or to challenge existing investigative designs or ideas (Driver, Newton, and Osborne, 2000). Whole classroom discussion can and does form an experiential basis from which to develop these important social processes of science culture.

III. Limitations of the study

This study focused on five teachers in four districts of a first-round LSC situated in southern New England. The data from two of the five sites was based on observing less than 70% of the unit's content. In addition, the researcher was not able to document the activities associated with the unit that took place beyond the assigned lesson times, such as Internet-based searches by learners, related readings by learners, or supplemental lessons taught by teachers.

Project administrators purposefully identified a pool of teachers for this study employing very specific criteria. Five teachers volunteered to participate in the study out

of 28. These 28 teachers represent less than 5% of the total number of teachers who participated in the TE project during the original funding period. The conclusions drawn from the data in this study are, therefore, highly specific to a subset of practitioners who were identified as exemplary and who volunteered for the study. They have extensive training beyond what most teachers in the LSC would have experienced.

The settings were assumed to be representative of the range of settings across the LSC. However, the LSC was chosen for this study because of the proximity and accessibility of sites to the researcher. The findings from this study are unique to the specific settings. As evidenced throughout this study, each district and school was structured very differently. Therefore, the environmental setting impacted the conditions of instruction and the expectations imposed on the teachers as elementary educators. But all of the schools supported science education.

The teachers in this study had a range of experiences with science and science teaching prior to their involvement with the LSC. For example, Rachel used text-based instruction and Natalie focused on life and Earth sciences prior to the adoption of the kit-based curricula. Tanya had extensive coursework in the traditional sciences as a nursing major. The extent to which these prior experiences impacted teachers' development of inquiry practice is not known. However, it was an underlying assumption on the part of the researcher that the teachers' understandings and beliefs about inquiry and the nature of science influenced their decisions and actions in the classroom.

The teachers in this study who were KS taught the units for which they were specialists. Therefore, they had an expertise with the materials that non-KS teachers may

not share. This ensured to some extent that teachers had extensive knowledge of and experiences with the materials they used.

The observation of teachers was limited to the instruction of a single unit taught at the beginning of the school year. There is no way to know how their instruction of science might vary with different content or over the course of the school year. Also impacting the interpretation of the findings was the amount of instruction observed. While it is difficult to discuss coverage of the horizontal curriculum quantitatively, it can be reasonably estimated that the observations ranged from 50% to 95% of the five units that were taught.

Each case-like study is unique and not all of the findings can be generalized beyond the context of the individual cases. The case-based findings were reviewed to determine if patterns and similarities existed across the five sites. The researcher's presence was another factor that impacted the setting during observations. Classrooms visited were rather small and the nature of the classroom design required movement around the classroom to document events. The extent to which this had an impact on learners' behaviors was not known. Teachers were asked about this during closing interviews. Teachers indicated that students were used to visitors in the classroom, therefore, while the impact of the researcher's presence was thought to be minimal, no attempt was made to monitor for observer effect. One teacher did make an adjustment to her teaching schedule to accommodate the researcher. The teacher limited her instruction as much as possible to an extended time block one day a week rather than using her two-day instructional sequence. The change to the teacher's instruction was discussed. During the study, the teacher felt she had to pay more attention to actively reflecting with

learners given that it would be another whole week before returning to science. The teacher viewed this as a positive impact.

Finally, all of the teachers were informed that the research was about looking at inquiry in teaching elementary science. There may have been a research effect on teachers' performances in their teaching as a result. However, this research was not intended to rank the relative capability or development of teachers' abilities to teach using inquiry. This was a descriptive inquiry of how science education was conducted in the selected settings.

The researcher selected the Five Essential Features of Inquiry as representative indicators of the Inquiry Continuum. While useful for describing inquiry teaching and learner experiences, the IC descriptions do not capture the complex nature of inquiry or science teaching.

Chapter Summary

The purpose of this chapter was to summarize key findings from the exploratory investigation of inquiry-oriented science teaching in elementary schools. The teachers observed in this study were exemplary practitioners at the elementary school level based on their commitment to professional development in science education and science teaching, and their extended use of kit-based, inquiry-oriented units with learners.

The Inquiry Continuum (IC) was employed as a descriptive tool for identifying five essential features of scientific inquiry in each classroom in this study. The IC served as a useful tool against which to analyze the observable behaviors of teachers and students during elementary school science lessons. The IC is not considered a complete articulation of the complex nature of scientific inquiry, but the IC does provide teachers

and researchers with a useful point from which to begin to reflect upon the practices and processes of good classroom inquiry. The IC is grounded in previous theory and research of science inquiry. Future studies will explore the IC as a tool for observing classroom instruction and interactions in the teaching of elementary school science. In this study the IC was an appropriate device to use, because it is grounded in the *National Science Education Standards* (National Research Council, 1996), which describes current reform goals.

The one feature of classroom inquiry requiring attention by the teachers in this study was teachers' use of learners' questions to guide students' inquiry investigations. The IC helped to illuminate this area as one requiring further attention by the teachers. This finding raises a question for further study and research: What PD experiences will continue to move teachers' practices to a fuller implementation of inquiry?

This study also identified that exemplary teachers of elementary science require professional development opportunities that promote teacher-designed investigations. The professional development experiences of teachers who have extensive experience with kits need to challenge teachers to become active investigators of their own questions and wonderings.

This research has identified two features necessary to move the current practices of the exemplary classroom teachers of science toward a fuller implementation of science inquiry – (1) teachers' acknowledgement of learners' questions in the active extension of kit-based curricula, and (2) teachers' investigations of their questions as an active component of their science instruction. Teachers require supportive approaches for

identifying and integrating instructional opportunities into an already rich approach to implementing inquiry in elementary school science.

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Appendices

Appendix A. iMovies Compact Disk (CD): Contact the researcher.

Natalie's Classroom: Water Movie

Rachel's Classroom: Electric Movie

Tanya's Classroom: Models & Design Movie

Allison's Movie: Insects Movie

Appendix B. LSC Teacher Survey

Part One: Teaching Information

1. The number of years teaching experience, including the 2002–03 academic year

_____

2. Grade(s) you are teaching this 2002–03 year (highlight and underline all that apply):

K 1 2 3 4 5 6 7 8

3. Specialty teaching that applies to your current/anticipated teaching assignments for the 2002–2003 school year (e.g., Special Education/Gifted Talented, ESL/Bilingual):

4. How many hours per week (approximately) do you teach science? ______

5. How many hours per week do you teach other subjects/content, such as Language Arts, Mathematics, and Social Studies? ________

Please, highlight and underline your responses to question six.

6. (a) Do you feel that you have a sufficient amount of time to teach science? YES NO

6. (b) Do you feel that you have sufficient support at school to teach science? YES NO

Part2: Academic Information

7. The highest academic degrees/certificates you hold (please underline all that apply):

Bachelors Masters CAGS Doctorate

8. Number of college science courses (*not credits*) you have taken:

Undergraduate = ________ Graduate = _________

Part Three: LSC PD & Kits

9. What academic year did you begin KITES training (e.g., 1996/97)? _____________

10. (a)The number of LSC professional development[5] hours you have accumulated to date (underline your response):

10. (b) Less than 100 hr. b. 100–149 hr. c. 150–199 hr. d. 200–249 hr. e. 250+ hr.

11. List the LSC kits you use/have used to teach science and indicate how long (how many years) you have taught each kit:

Kit Titles	Number of Years Kit was Taught

12. Are you or have you ever been a Kit Specialist, KS (underline your response)?

YES NO

[5] Professional Development (PD) means any courses, workshops, institutes, coffees, reflection sessions, retreats, trips, etc. that focus on improving and sharing science knowledge and teaching.

Appendix C. Teacher Interview Questions.

I. Inquiry

1. In your own words, describe what “inquiry” is.
2. As you reflect on your science teaching, can you describe what you do to make your teaching “inquiry-based”?
3. As an observer in your classroom interested in inquiry, what might I expect to:

   (a) See you doing related to “inquiry teaching”?

   (b) See students doing related to “inquiry learning”?
4. How would you describe students’ responses:
5. To your inquiry instruction?
6. To the inquiry processes?
7. How do you assess learners’ growth toward meeting this standard?

II. Nature of Science (NOS)

1. Describe the nature of science, as you understand it—what is the nature of science?
2. How is “scientific inquiry” related to inquiry?
3. As you reflect on your teaching of science, how do you convey the nature of science to learners? Give representative examples from your experiences.

III. Professional Development (PD)

1. What types of PD do you feel have best prepared you to teach science using an inquiry approach to instruction?
2. What experiences do you attribute to your current understanding of inquiry?
3. What aspects of inquiry are you comfortable with in your teaching?
4. What aspects of inquiry, if any, do you find challenging to your teaching of science?
5. How would you describe your growth in as a teacher of science from the time you entered teaching to the present?
6. What next steps do you see or plan for continuing to grow in your understanding of science teaching?

Appendix D. Postobservation Interview Questions

1. How do you think the unit went overall?
2. What aspects of inquiry do you think the kit you taught supports/doesn't support?
3. Was the student performance with the kit I observed typical of your experiences teaching it? Prompt: Based on your prior experiences teaching this kit, did learners perform pretty much as you expected—how were you surprised or disappointed by learner performances?